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SOME PHYSICAL PROPERTIES OF SOILS

IN THEIR RELATION TO

MOISTURE AND CROP DISTRIBUTION.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., July 28, 1892.

Sir: I have the honor to transmit herewith a paper entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution," prepared by Prof. Milton Whitney, of Johns Hopkins University, and to recommend its publication as Weather Bureau Bulletin No. 4. In this connection I would state that this is the second paper of a series on the relations of soils to meteorology, the object of which is to elicit information from specialists, rather than to indicate the views held by the Department on the subjects treated.

Very respectfully,

Mark W. Harrington,
Chief of Weather Bureau.

Hon. J. M. Rusk,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., July 1, 1892.

SIR: I have the honor to submit herewith my report entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution."

The work for the Department has covered a period of only six and a half months and on the soils of Maryland of only a few months longer. Much of this time has necessarily been spent in collecting material and in other preliminary work. The work is to be continued and the physical properties and conditions of these soils will be studied in still more detail.

This report is based partly on my own original work and partly on a generalization of the work of others in this line, as reported in the literature of the day. The limits of this report would not allow of the presentation of even the main facts from which these generalizations have been drawn, which are well known, however, through the admirable writings of Johnson and Storer, or of the views generally held by agricultural chemists as to the cause of the local distribution of plants. It is believed, however, that although these views and generalizations may appear at first sight to differ from the present theory of fertilization, a more careful consideration will show that they supplement rather than conflict with the views commonly held by agricultural chemists.

Very respectfully,

MILTON WHITNEY.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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SOME PHYSICAL PROPERTIES OF SOILS IN THEIR RELATION TO MOISTURE AND CROP DISTRIBUTION.

INTRODUCTION.

The history of soil investigations forms a very interesting chapter in scientific literature. It has not been many years since it was generally believed that the chemical analysis of a soil would show what class of plants the soil is best adapted to produce, and what elements of plant food are lacking in the soil for the best development of other crops. It was found, by a vast amount of work on the chemical composition of soils and plants, that all soils contain a large amount of plant food, while the relatively small amount removed by crops in a series of years can not be detected by chemical means, although, as the result of injudicious methods of culture during this period, the soil may deteriorate and the yield of crop fall below the limit of profitable cultivation. It was then believed, and it is still held, that only a small proportion of the plant food in the soil is in such a form as to be readily available to plants, and that this may readily revert to an insoluble or unavailable form if it is not quickly used up by plants.

Various solvents have been suggested and tried to determine the amount of available plant food in the soil. Plot experiments with manures and fertilizers have been carried out to ask of the soil the direct question, what amount of available plant food is needed in order to insure a maximum crop.

Some rather anomalous facts have been shown in this work. A plant having a large amount of nitrogen, for example, in its composition, will not necessarily respond to a manuring with this particular ingredient, but will respond readily to a manuring of another substance, of which it uses only a relatively small amount, while other plants, containing a small amount of nitrogen in their composition, will respond readily when manured with this substance, even on the same land. This is supposed to be due to a difference in the feeding capacity of the plants. A plant which responds readily to a nitrogenous manuring one year may respond more readily to a phosphatic manuring on the same soil the next year if the *season* is different. The standard fertilizing materials frequently give a lower yield of crop than is produced where nothing has been added to the soil; and, on the other hand, a very small addition of a fertilizer may increase the crop to an extent out of all proportion to the amount of

plant food added to the soil. This is especially true of stable manure and lime.

There has been no satisfactory interpretation, as yet, of much of the work which has been done on the chemical composition of soils and plants, and the results of plot experiments have, in most cases, been very conflicting and uncertain.

The physical conditions of growth have been recognized as of importance, and of controlling importance in many cases, but their influence has hardly been considered in soil investigations. Records have been carefully kept of all the ordinary meteorological conditions and atmospheric changes, but there has been, in most cases, no interpretation of the results; and the results have been given and remain as a mass of unintelligible and seemingly useless figures.

The distribution of our staple crops, according to the meteorological conditions which prevail in the country, has been very ably discussed by Brewer in the tenth census. It is undoubtedly due to these meteorological conditions, rather than to any difference in plant food or in methods of cultivation, that the average yield of grain per acre in the Southern States is only about one-third of that in the North and West. The conditions at the South are more favorable to long continued growth of leafy matter, and it is difficult to check the growth of the plant and make it produce a fair yield of grain. It is only since the introduction of commercial fertilizers, which have hastened the ripening of the crop, that cotton has been successfully grown as far north as the upper counties of North Carolina, and it is only by improved methods of cultivation that the Sea Island cotton has been made to mature within the season which prevails in South Carolina. Temperature, of course, is a very important factor in plant development, and this alone determines the general distribution of many plants, and prevents tropical fruits being produced in the short season of the Northern States. It is not that the soils of Pennsylvania are less rich in plant food than the soils of Florida, or that the plant food is in a different form of combination, but that temperature is the controlling cause in crop production. This is such an every-day matter that it is hardly realized that temperature is such a potent factor in the distribution of crops, and that even our own seasonal changes must have a more important effect on the development of plants than is usually considered. But even over small areas, where the meteorological conditions cannot be very different, the texture of the soils may be so different that they maintain very different conditions of heat and moisture for the growing crops. In these local conditions, moisture seems to be far more important than heat, and the relation of the soil to moisture largely determines the relation of the soil to heat. However potent, therefore, the factor of temperature may be in the general distribution of crops, the relation of soils to moisture, or the amount of

moisture they may maintain under existing meteorological conditions, is quite as important a factor in the local distribution and development of plants. The texture of the soil and its condition and treatment have been recognized as of importance in determining crop distribution and development, but there has been no interpretation or expression of these physical conditions of the soil which could be used in the calculation of results of the soil investigations. It is proposed in this paper to show that the physical properties of soils very largely determines the local distribution and development of plants, and to suggest methods for the study and expression of the physical properties and condition of the soil.

A preliminary report of these soil investigations was published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, and this will be freely used in the present paper, as well as some unpublished matter on investigations of a similar character, carried on by the writer at the South Carolina Experiment Station.

In the older agricultural regions of the country in the Eastern and Southern States, especially below the influence of the glacial action, there are many large areas of well marked and very uniform soil conditions, corresponding to different geological formations, where the distribution and production of crops seem to be dependent upon the texture of the soil. There is a certain type of land in certain geological formations which is so coarse and open in texture that it is permitted to remain in pine barrens; there is another type bordering the coast, in a different geological formation, which is well suited to melons and early vegetables; still other types of soil are suited to different grades of tobacco and to wheat and grass.

The agricultural chemist has approached this subject through the study of the chemical composition of soils and plants, and has attempted to explain the distribution of plants through the minute differences in chemical composition or in the form of chemical combination of the ingredients in the soil. The practical farmer, on the other hand, can judge much more correctly of the condition of the land and what it is best fitted to produce, from the general appearance or physical texture and structure of the soil. It is a matter of common experience to him to judge from the texture and general appearance of the soil what crop it is best fitted to produce, and what general treatment should be pursued in the production of the desired crop. He knows that wheat can not be economically produced on light sandy lands, under prevailing climatic conditions, and that no addition of mere plant food will cause a good wheat crop to be produced on such a soil without resorting to irrigation, where the water supply can be controlled, or without first changing the texture of the soil so as to make it more compact and more retentive of moisture, so that it can maintain a more abundant supply of water for the crop. It is a

matter of the available water supply maintained by the soil rather than of the available plant food which determines this local distribution of plants. Under the same climatic conditions the wheat land will maintain two or three times as much moisture for the use of the crop as the light sandy lands. If the conditions in the wheat land are normal, and are necessary conditions for the wheat crop, which can not be doubted in view of the number of determinations which have been made, then there is something radically wrong in the light truck land as a wheat soil, and this relation of the soil to moisture becomes as potent a factor as a controlling cause as temperature is in the economical production of oranges, bananas, and pineapples in the Northern States.

It may be objected that not enough importance is given to the chemical side in this treatment of the subject, but if the relation of the soil to moisture is conceded to be a controlling cause in the local distribution of wheat on these two types of soil, as would be claimed in this case by any practical farmer, then this alone is to be considered first, and all changes, treatment, and improvement of the land must be along this line. A farmer is a man of rare experience and observation in these lines, and is to be relied on in matters of fact, however much those of us who are engaged in purely scientific work may disagree with him in deductions from these facts. The facts themselves must be accepted and be the basis for scientific work. How common it is in the improvement of lands to hear of a refractory clay being made more loamy by judicious treatment, and a loose, incoherent sand being made more retentive of moisture.

Now it seems that there must be some explanation, some interpretation, and some expression of this fact that the farmer can judge of the agricultural value of a land and the kind of crop which it can or can not produce, from the general appearance of the land, that is, from the physical texture and structure of the soil. It would seem that this must come through the proper interpretation of the mechanical analyses of soils. The results of the mechanical analyses, as usually given, have little meaning, for there is little or no attempt at the interpretation of the results, and there is no expression of the results which can be used in forming a definite opinion of the character of the land.

It is proposed to suggest here an interpretation of the mechanical analyses of soils which shall explain and define these visible signs upon which the practical farmer bases his judgment of the agricultural value and condition of the soil, and which can be used, in relative terms at least, in the expression of results of soil and plant investigations.

It will be necessary first to discuss some of the fundamental principles upon which this interpretation is based and then to present prob-

lems with an application of the principles. The primary conceptions upon which this is based may be briefly stated as follows: The circulation of water in the soil is due to gravity, or the weight of water, acting with a constant force to pull the water downward, and *also* to surface tension or the contracting power of the free surface of water (water-air surface), which tends to move the water either up or down or in any direction, according to circumstances. The ordinary manures and fertilizers change this surface tension, or pulling power, of water.

There is a large amount of space between the grains in all soils, in which water may be held. The rate of movement of the water will depend upon how much space there is in the soil; upon how much this space is divided up, *i. e.*, upon how many grains there are per unit volume of soil; upon the arrangement of the grains of sand and clay; and upon how this skeleton structure is filled in and modified with organic matter.

The arrangement of the grains, and consequently the texture or structure of the soil, may be changed through the effect of the ordinary manures and fertilizing materials, causing flocculation or the reverse.

THE CIRCULATION OF WATER IN THE SOIL.*

The motive power which causes water to move from place to place within the soil consists of two forces: gravity, or the weight of the water itself, and surface tension. Gravity tends to pull the water downward, and acts with a constant force per unit mass of water, neglecting the slight difference due to elevation and to latitude. Surface tension, or the contracting power of any exposed water surface, may move the water in any direction within the soil, according to circumstances. It may act, therefore, with gravity to pull the water down, or against gravity to pull it up. The force of gravity need not be further considered here.

Surface tension is the tendency which any exposed surface has to contract to the smallest possible area consistent with the weight of the substance. If a mass of water is divided, or cleft in two, leaving two surfaces exposed to the air, the particles of water on either surface, which were before in the interior of the mass and attracted from all sides by like particles of water, have now water particles on only one side to attract them, with only a few air particles, comparatively very far apart, on the other side, where formerly was a compact mass of water. All the surface particles of water will therefore be pulled from within the mass of water, and the surface will tend to contract as much as possible, leaving exposed the smallest number of

*Much of the discussion of these underlying principles is taken from a preliminary paper in the Fourth Annual Report of the Maryland Agricultural Experiment Station.

surface particles, and causing a continual strain or surface tension. On any exposed water surface there is always this strain or tension ready to contract the surface when it may.

It is a constant, definite force per foot of surface for any substance at a given temperature. In the case of liquids and solutions, in which we are most interested, it varies with the nature of the liquid and the substance in solution.

This is surface tension; and we have it in the soil as a strain or tension along the free surface of water within the soil, which tends to contract the surface and so move the water from one place to another as it is needed.

There is, on an average, about 50 per cent. by volume of space within the soil which contains no solid matter, but only air and water. This we shall call empty space. In a cubic foot of water there is about half a cubic foot of empty space, but this is so divided up by the very large number of soil grains that the spaces between the grains are extremely small.

When a soil is only slightly moist the water clings to the soil grains in a thin film. It is like a soap bubble with a grain of sand or clay inside, instead of being filled with air. Where the grains come together the films are united into a continuous film of water throughout the soil, having one surface against the soil grains and the other exposed to the air in the soil. As the soil grains are surrounded by this elastic film, the tension on the exposed surface of the water will support a considerable weight, for the soil grains, thus enveloped, are extremely small and have many points of contact around which the angle of the surface is more acute and the film is thicker and is held with greater force.

If more water enters the soil the film thickens, and there is less exposed water surface. If the empty space is completely filled with water there will be none of this exposed water surface, and, therefore, no surface tension. Gravity alone will act and with its greatest force. If the soil is nearly dry there will be a great deal of this exposed water surface, a great amount of surface tension, and, with so little water present, gravity will have its least effect.

The grains in a cubic foot of soil have, on an average, no less than 50,000 square feet of surface area. There is less, of course, in a sandy soil, and more than this in a clay soil. If there is only a very small amount of water in the soil the film of water around the grains will be very thin, and there will be nearly as much exposed water surface as the surface area of the grains themselves. If a cubic foot of soil, thus slightly moistened, and having this large extent of exposed water surface, be brought in contact with a body of similar soil fully saturated with water, in which there is none of this water surface, the water surface in the drier soil will contract, the film of water around

the grains will thicken, and water will be drawn from the wet into the dry soil, whether it be to move it up or down, until, neglecting gravity or the weight of water itself, there is the same amount of water in the one cubic foot of soil as in the other. When equilibrium is established there will be the same extent of exposed water surface in these two bodies of soils.

When water is removed from a soil by evaporation, or by plants, the area of this exposed water surface is increased, and the tension tends to contract the surface and pull more water to the spot.

When rain falls on rather a dry soil the area of the exposed water surface in the soil is diminished, and the greater extent of water surface below contracts and acts, with gravity, to pull the water down.

Fertilizers change this surface tension and modify the contracting power of the free surface of water to a remarkable degree, and so modify the power which moves water from place to place in the soil.

The following table gives the surface tension of a solution in water of several of the ordinary fertilizing materials. The surface tension is expressed in gram-meters per square meter, that is, on a square meter of liquid surface there is sufficient energy to raise so many grams to the height of one meter.

Where the substance was sufficiently soluble the solution was made up to a specific gravity of 1.1000, but where the substance was not sufficiently soluble for this, 10 grams were digested for twenty-four hours with 100 cubic centimeters of distilled water. All the solutions were filtered through washed filters before being used. The ordinary city supply, from a faucet in the laboratory, was used for the determinations made last year, contained in the first part of the table; and such water is usually considered the best for such work, as the water is drawn out of a large body from below the surface. For the later results, however, ordinary distilled water had to be used, but all the water used was taken from the same supply and was siphoned off when needed:

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Number of measurements from which the mean is taken.	Mean.	Highest.	Lowest.
Salt	1.070	6	7.975	8.126	7.796
Kainit	1.053	6	7.900	7.993	7.805
Lime	1.002	4	7.696	7.750	7.674
Water	1.000	18	7.668	7.923	7.506
Acid phosphate	1.005	4	7.656	7.800	7.563
Plaster	1.000	9	7.638	7.730	7.572
Ammonia	0.960	6	6.869	6.950	6.826
Urine	1.026	10	6.615	6.740	6.471

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Surface tension.	Solution of—	Specific gravity.	Surface tension.
Magnesium chloride	1.1000	7.964	Wood ashes	1.0038	7.674
Common salt	1.1000	7.911	Potassium nitrate	1.1000	7.661
Muriate potash	1.1000	7.907	Potassium sulphate	1.0830	7.658
Thomas slag	1.0012	7.890	Ammonium nitrate	1.1000	7.656
Kainit	1.1000	7.889	Dried fish	1.0026	7.594
Marl	1.0013	7.855	**Water**	**1.0000**	**7.532**
Potassium chloride	1.1000	7.853	Stable manure	1.0013	7.464
Ammonium sulphate	1.1000	7.834	Acid phosphate	1.0104	7.414
Dried blood	1.0001	7.764	Cotton-seed meal	1.0054	6.534
Ground bone	1.0007	7.749	Tankage	1.0169	4.844
Sodium nitrate	1.1000	7.730	Cotton seed	1.0070	4.788
Sodium sulphate	1.1000	7.730			

Surface tension of soil extracts.

No.	Soil.	Specific gravity.	Surface tension.
295	Kentucky blue grass	1.000	7.244
281	Triassic red sandstone	1.000	7.244
279	Wheat	1.000	7.098
....	Garden	1.000	7.089

The determination was made by the method of the rise in a capillary tube. A short piece of thermometer tubing was used, the diameter of the bore being determined by careful microscopic measurements with a micrometer eye piece. Sections of the tube, above and below the piece taken, appeared very uniform and so nearly circular as to be within the limit of error of observation. The diameter of the tube was taken at 0.5578 millimeters, and the figure 0.0558 centimeters was used in the calculation of the results. The tube was very thoroughly cleaned after each observation, or set of observations, with a strong caustic potash solution, and, after washing, was allowed to stand for some time in a saturated solution of bicromate of potash in strong sulphuric acid. The height of the rise in the capillary tube was measured with a cathetometer.

The following formula was used for the calculation of the results:

$$T = \frac{h\ d\ \omega}{4\ cos.\ a}$$

Where T is the surface tension; d is the diameter of the tube in centimeters; h the height to which the liquid rises in the capillary tube in centimeters; ω is the specific gravity of the solution; and 4 *cos. a* refers to the angle of the liquid with the side of the glass tube. In regard to this latter, 5° 24′ was taken as the edge angle. This is the mean of 11 determinations given by Quincke of the edge angle of pure water and glass.* In regard to saline solutions, Quincke says, that "according to these researches the edge angle

*Quincke on edge angle and spread of liquid on solid bodies, Phil. Mag., 1878.

appears to increase a little with augmenting concentration of the saline solution, but otherwise, to differ only inconsiderably from the edge angle of pure water."

In regard to the results themselves, most of the salts have increased the surface tension of the water, while the organic matters have generally lowered it. Cotton-seed meal, tankage, and cotton seed have lowered the surface tension very considerably. The determinations of the surface tension of these three substances were not very satisfactory, as the solutions were very viscous and moved very slowly in the capillary tube, continuing to fall for a long time after the tube had been immersed and raised again in position for the reading. The very low result with the cotton seed is probably due to the oil, most of which is expressed in the preparation of the meal.

Cotton seed and cotton-seed meal are both used as fertilizers in large quantities at the South. Opinion seems to be very evenly divided as to which gives the better results; some claiming good results from the one and rather injurious results from the other. It has been argued that as the oil has no fertilizing value its presence can do no good in a fertilizer, but on the contrary may do harm, by preserving the substance from disintegration and solution; and it has been argued that it is not only a profit to the cotton planter to have his seed converted into meal, from the value of the oil obtained, but that the value of the product itself is increased as a fertilizer. There are so many positive statements, however, of the greater value of the seed on certain soils than of cotton-seed meal, that I cannot but think in some soils or under some conditions the oil in the seed must have a beneficial effect, apart from any slight fertilizing value it may have, in its effect on the physical condition of the soil due to this very low surface tension of its extract, and in the effect which it may have on the arrangement of the soil grains through flocculation or the reverse.

It has frequently been observed that an application of magnesium chloride, salt, or muriate of potash tends to keep the soil more moist in dry weather. These substances have the highest surface tension of any in the table. They would tend to increase the surface tension of the soil moisture and increase the power the soil has of drawing water up from below, and it is probably this which explains the action of these salts referred to.

On the other hand, the injudicious use of concentrated organic matters in a dry season may "burn out" the land and make it drier than it would otherwise be, as the organic matter would lower the surface tension of the soil moisture and the soil would have less power of drawing water up from below for the support of crops; although their judicious use in favorable seasons would tend, in another way, to make the soil more retentive of moisture, as will be shown.

The surface tension of several soil extracts are given in the table,

and these are seen to be very much lower than that of pure water. The extracts were made by rubbing up 10 grams of the subsoil with just sufficient water to cover it, and this was allowed to digest for twenty-four hours, being frequently stirred. The extracts were, in most cases, turbid, but the matter in suspension was so fine that it could not be removed with a filter.

The contact of the water with the subsoil lowered the surface tension very considerably, but as this extract was still very much more dilute than the ordinary soil moisture the surface tension of the soil moisture itself must be assumed to be considerably lower than the tension of these extracts. It was not considered advisable at this time to extend these investigations further, although there is an opening here for some interesting work.

There is a very interesting application of this low surface tension of soil moisture. It is a matter of very common experience with gardeners that if a plant or piece of lawn is watered in a very dry season, by applying water to the surface of the ground, the watering has to be continued thereafter during all the dry season, as the result of a single watering is to leave the ground drier than it would otherwise have been. They usually put off watering as long as possible for this reason, and when they once begin they continue it. King has proved this experimentally by watering a piece of ground and letting it stand for twenty-four hours. He then found by direct determinations that the upper foot was wetter than immediately before the watering, but that the lower depths of the soil, down to 36 inches deep, were drier than before the watering. It would seem in this case that the higher surface tension of the pure water, or of the more dilute soil moisture in the surface soil, had pulled up water from below, where the surface tension is less, and the danger would be that this water being brought near the surface would then evaporate quickly, and so more of the original soil moisture would be lost by evaporation than if the water had not been applied to the surface.

Several years ago the writer called attention to the interesting fact that the level of the water in the wells in the grounds of the Agricultural Society in Raleigh, N. C., was lowest during the winter months and gradually rose, notwithstanding the spring and summer droughts, reaching its maximum about August. Goff published similar observations on a well at the New York Experiment Station. In the Sand Hill formation at Columbia, S. C., the wells are at their fullest during excessive dry weather, but immediately begin to fall after a soaking rain following a long dry spell. The application of the foregoing principles seems apparent here, that as the soil becomes drier the surface tension of the soil moisture is reduced so that it can not maintain the water at the same height as formerly. The water from the lower depths of the subsoil is, therefore, let down into

the well as the surface soil becomes drier and the surface tension of the moisture in the upper layers of the soil is diminished through concentration of the solution. With a soaking rain, the pure water increases the surface tension of the moisture in the upper layers of the soil, and while there is less extent of surface to contract, the greater contracting power more than counterbalances this and water is drawn up from below, or, at least, does not flow so readily into the well.

To sum up, it may be briefly stated that the surface tension, or lifting power of soil moisture, is much lower than that of pure water. Many of the common fertilizing materials increase this surface tension of the soil moisture and increase the power the soil has of drawing water up from below in a dry season, or of drawing water to a a plant to replace that which has been lost by evaporation or has been used up or transpired by the plant. On the other hand, many organic substances lower the surface tension, or pulling power, of water very considerably and lessen the power the soil has of pulling water up from below to supply the loss due to evaporation, or what has been used by plants.

This effect of fertilizing materials in changing the surface tension of a liquid, and thereby changing the force or power which moves water from place to place in the soil, is only a first effect, as the continued use of these fertilizing materials may change the texture of the soil itself and the relation of the soil to the circulation of water.

THE EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

Surface tension may be expressed in another way.* The potential of a single water particle is the work which would be required to pull it away from the surrounding water particles and remove it beyond their sphere of attraction. For simplicity, it may be described as the total force of attraction between a single particle and all other particles which surround it. With this definition it will be seen that the potential of a particle on an exposed surface of water is only one-half of the potential in the interior of the mass, as half of the particles which formerly surrounded and attracted it were removed when the other exposed surface of water was separated from it. A particle on an exposed surface of water, being under a low potential, will therefore tend to move toward the center of the mass where the potential, *i. e.*, the total attraction, is greater, and the surface will tend to contract so as to leave the fewest possible number of particles on the surface.

*This treatment of the subject was suggested by an article by Lord Rayleigh in the Phil. Mag., Nov. and Dec., 1890; and I am further indebted to Dr. Arthur L. Kimball, formerly of the Johns Hopkins University, but now of Amherst, Mass., for much valuable advice and suggestion in the application of the principles to the phenomenon of flocculation.

If instead of air there is a solid substance in contact with the water, the potential will be greater than on an exposed surface of the liquid, for the much greater number of solid particles will have a greater attraction for the water particles than the air particles had. They may have so great an attraction that the water particle on this surface, separating the solid and liquid, may be under greater potential than prevails in the interior of the liquid mass. Then the surface will tend to expand as much as possible, for the particles in the interior of the mass of liquid will try to get out on to the surface. This is the reverse of surface tension. It is surface pressure, which may exist on a surface separating a solid and liquid.

This probably explains the phenomenon of flocculation, a phenomenon of very great importance in agriculture.

Muddy water may remain turbid for an indefinite time. If a trace of lime or salt be added to the water the grains of clay *flocculate*, that is, they come together in loose, light flocks, like curdled milk, and settle quickly to the bottom, leaving the liquid above them clear. Ammonia and some other substances tend to prevent this and to keep the grains apart, or to push them apart if flocculation has already taken place. This is similar to the precipitation of some solid matters from solution. When lime is added to a filtered solution of an extract of stable manure, the organic matter is precipitated in similar loose, bulky masses. This matter of potential would seem to have a bearing on all cases of precipitation, as the phenomena of flocculation and precipitation are really quite similar. It would seem to be one of those points between physical and chemical forces which have been sharply marked in the past, but which are now fast disappearing as these two sciences are coming closer together.

If two small grains of clay, suspended in water, come close together they may be attracted to each other or not, according to the potential of the water particles on the surface of the clay. If the potential of the surface particle of water is less than the particle in the interior of the mass of liquid, there will be surface tension, and the two grains will come together and be held with some force, as their close contact will diminish the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than of the particle in the interior of the mass, the water surface around the grains will tend to enlarge, as there will be greater attraction for the water particles there than in the interior of the mass of liquid, and the grains of clay will not come close together and will even be held apart, as their close contact would diminish the number of surface particles in the liquid around them.

This hypothesis would seem to be easy to prove experimentally, and it was hoped that this could be done in time for this report, but there has not been time, although the apparatus has been ready for some months.

Much interesting work has been done by Hilgard, Brewer, and Carl Barus on this matter of flocculation. They all assume a chemical hydration of the fine particles of clay as an important factor in the suspension of the clay in water, and of de-hydration by salt or lime, in the flocculation of a turbid liquid. While such hydration and de-hydration may occur, it does not seem at all necessary for the continued suspension and almost indefinite suspension under ordinary conditions of fine clay particles in a turbid liquid. I can not agree with Brewer that clay particles are ultra-microscopic, although they are exceedingly small and very difficult to define. In a turbid liquid which has stood for several weeks and is only faintly opalescent, a drop of the liquid carefully evaporated on a cover glass, ignited and stained, as in ordinary bacteriological examinations, will show particles under an oil emersion objective, not very sharply defined to be sure, under such a high power, but still of measurable size, ranging from about $\frac{1}{10}$ of a space of my eye-piece micrometer to about $\frac{1}{2}$ of a space. The lower limit would give a value of .0001 millimeter and as this has been verified a number of times in turbid liquids which have stood so long as to be only faintly opalescent, I have assigned this as the lowest limit of my "clay" group, pending further and more exact determinations in which a turbid liquid shall be examined at frequent intervals during subsidence, and where precautions have been taken to destroy and exclude bacteria.

Fine dust and ashes, and even filings of metals, remain in suspension in the air for days and even months in very apparent clouds or haze, although they may be a thousand times heavier than the surrounding air. Particles of clay, no smaller than the limits which have been assigned, should remain in suspension in the much heavier fluid water for an indefinite time, for the volume or weight of a sphere decreases so much more rapidly in proportion than the surface, that there is relatively a large amount of surface area in these fine particles and a great deal of surface friction in their movement through a media, and they would settle very slowly. This is clear from the following calculation:

The volume of a sphere $= \frac{4}{3} \pi r^3$

The surface of a sphere $= 4 \pi r^2$

The volume or weight decreases proportionately faster than the surface area. For, consider a sphere of a radius of one inch. The volume will be $\frac{4}{3} \pi 1^3$ and the surface $4 \pi 1^2$. If, now, this sphere be reduced in size until the radius is $\frac{1}{100}$ of an inch, the volume will be $\frac{4}{3} \pi \frac{1}{1000000}$ and the surface of the sphere will be $4 \pi \frac{1}{10000}$.

If we assume now the mean diameter of several of our separations in a mechanical analysis we will have the following values:

Diameter 1.5 millimeters, fine gravel.

Diameter 0.075 millimeters, very fine sand.

Diameter 0.00255 millimeters, clay.

If we assume the volume, or weight, of the gravel to be unity, then for very fine sand—

The volume decreases in the ratio 1 : 0.000125.
The surface decreases in the ratio 1 : 0.2556.

For clay—

The volume decreases in the ratio 1 : 0.000000004853.
The surface decreases in the ratio 1 : 0.000286.

If the lowest value given above is assumed for the diameter of the clay particle (.0001 millimeter) the ratio would be, of course, still more striking. As it is, the relatively large surface area of these fine particles would allow them to subside only with extreme slowness, and it would probably seem that under ordinary conditions, in which the mean daily range of temperature is 20°, the mean monthly range 50°, and the yearly range 100° F., that the ordinary convection currents, induced by this normal change of temperature, would be sufficient of itself to keep these fine particles in suspension in the liquid for an indefinite time, as it is known that currents of air keep fine particles of dust in suspension. It does not seem as though it were necessary to consider the chemical hydration hypothesis to explain the suspension of fine particles in water; nor the de-hydration hypothesis to explain the flocculation of clay, when the grains, under a low potential, can come within the sphere of their mutual attraction and fall or rise together in a loosely united mass.

This matter of flocculation has a most important bearing on the arrangement of the soil grains, and the relation of the soil to water. It will be remembered that there is, on an average, about 50 per cent. by volume, of empty space within the soil. This empty space is divided up by a vast number of grains of sand and clay. If these grains are evenly distributed throughout the soil, so that the separate spaces between the grains are of nearly uniform size, water will move more slowly through the soil than if the grains of clay, through flocculation, adhered closely together and to the larger grains of sand, making some of the spaces larger and others exceedingly small.

The movement of water through capillary tubes is according to the *fourth* power of the radius. If we have ten capillary tubes of equal size, and ten other tubes with the same total area of cross section, but with one of the tubes large and the other nine tubes exceedingly small, water will move much faster through these tubes of uneven size than it will through the others.

We have, then, this principle to work on in the improvement of soils. In a close, tight clay in which water moves slowly, the continued use of lime may cause flocculation; the grains of clay will move closer together, leaving larger spaces for the water to move

through. This is undoubtedly the trouble in the clays of the Potomac formation in Maryland, the grains are very evenly distributed and the flow of water is so extremely slow that the soil is practically impervious to water. In such a soil a rapidly growing plant might perish for lack of sufficient water supply, when it was shown by analysis that the soil contained a large amount of water. The movement of water would be so slow that the soil could not supply the plant with water rapidly enough for its need, and the plant would suffer for water as in a light sandy land.

On the other hand, there are soils in which the clay is held so closely to the grains of sand as to give the soil the appearance and properties of a sandy soil, although there is as much clay present as there is in many of the distinctively "clay" lands. This will be shown very clearly in speaking of the Wedgefield, S. C., soils, in another place. We will speak of this matter more at length when we come to speak of the application of these principles to the improvement of soils. Most of our work has been on the determination of the approximate number of grains per gram, to show how much the empty space in the soil has been divided up; and this matter of the determination of the arrangement of the soil grains in their natural position in the field has hardly yet been taken up.

This movement or rearrangement of the soil grains could readily occur in a soil, even if the soil were only slightly moist, for the diameter of the fine silt and clay particles would be much less than the mean thickness of the film of water in the soil, and they could move freely as though they were immersed in a relatively deep fluid. The forces which move them, as will be shown later, are changing moisture content and possibly changing atmospheric pressure, while the condition which determines their close contact will be the surface tension or potential around the soil grains; and this can be changed, as we have seen, by the different fertilizing materials, when the grains will assume a closer or a looser arrangement.

THE VOLUME OF EMPTY SPACE IN SOILS.

There is, on an average, about 50 per cent. by volume of empty space in soils. The amount in the soil proper will vary with the state and stage of cultivation, but the empty space in the undisturbed subsoil will remain fairly constant. The amount of space in the soil may be found by completely filling a short depth of a known volume of soil with water. The weight of the soil before and after the introduction of the water will give the weight of water or the volume of the space. Or the amount of empty space may be found by calculation from the weight of a known volume of soil and the specific gravity. The weight of a known volume of soil in its natural position in the field can be determined as follows: An iron or brass tube, about 2

inches in diameter and 6 or 9 inches long, is driven into the ground to a depth of 6 inches. The tube is then dug out, a knife being passed under the lower edge to cut off the cylinder of soil in the tube. The soil is then carefully removed, dried, and weighed.

From the weight of soil and the volume of the tube, the volume of empty space may be found by the following formula:

$$S_1 = \frac{\left(V - \frac{W}{w}\right) \times 100}{V}$$

Where S_1 is the per cent. by volume of empty space, V is the volume of the tube in cubic centimeters, W is the weight of soil in grams, and ω is the specific gravity of the soil.

At first a piece of 2-inch boiler tube was used for taking the samples, one end of the tube being turned off in a lathe to give a good cutting edge. It was found, however, that the friction against the inside of the tube forced the cylinder of soil down a little so that it was feared that the weight of soil would be too light. Such a tube was used in the South Carolina work. In the more recent work a brass tube has been used, which has a clock spring securely soldered in one end, which is turned off in a lathe to give a good cutting edge of hard steel. The area inclosed by this cutting edge has been accurately determined. The tube is 9 inches long, with a mark on the side of the tube 6 inches from the cutting edge, and the tube is driven down into the soil until this mark is even with the surface of the ground. The advantage of this arrangement is that the clock spring cuts out a cylinder of soil of a definite area of cross section and friction is reduced to a minimum, while the soil can be readily removed from the tube. The sampling may be done for every 6 inches down for any desired depth.

The per cent. by volume of empty space varies from about 35 per cent. in the undisturbed subsoil of a coarse, sandy land to 65 or 70 per cent. in the subsoil of a strong clay land.

In "How Crops Feed," Johnson gives the weight of a cubic foot of sandy land at 110 pounds, and a cubic foot of clay soil at 75 pounds. Assuming 2.65 as the specific gravity of the soils, this would give about 34 and 55 per cent. by volume of empty space, respectively, in these soils.

The term "light soil" is thus commonly applied to that which actually weighs a good deal more than what is called a "heavy soil." The terms refer to the texture of the soils and the ease with which they can be worked.

The amount of space has been determined in a number of subsoils in South Carolina, in their natural position in the field, including a wide range of soil formations. The per cent. by volume of empty space is given in the following table:

Empty space in South Carolina subsoils.

(Per cent. by volume.)

78.	Wedgefield (sandy land)	41.80
66.	Gourdins	42.82
57.	Sumter	44.10
80.	Lesesne	46.41
57*a*.	Sumter	47.70
69.	Gourdins (Mr. Roper)	49.74
64.	Lanes	50.00
74.	Wedgefield ("Red Hill" formation)	50.03
69*a*.	Gourdins	50.25
53.	Charlotte, N. C.	52.05
71.	Gourdins ("bluff land")	55.40
53*a*.	Charlotte, N. C	57.19
76.	Wedgefield ("gummy land")	58.46
76*a*.	Wedgefield ("gummy land")	61.54
42.	Chester ("pipe clay")	65.12

The amount of empty space has been determined in only a few of the Maryland soils, with the following results:

Empty space in Maryland subsoils.

(Per cent. by volume.)

246.	Truck land, Tick Neck	37.29
246.	Truck land, Shipley	39.00
563.	Truck land, Armiger	41.25
478.	Wheat and late truck, Shipley	42.72
567.	Truck land, one mile west of Armiger	43.90
579.	Truck land, Rock Point	45.54
592.	Barren Potomac clays	47.19
599.	Wheat land, South River	51.48

As opportunity offers, these determinations will be made in other parts of the state, especially in the heavier soils of western Maryland.

The following values have been used in all of our work, the specific gravity in all cases being taken as 2.65:

Per cent. by volume of space.	Weight of unit volumes of soil.		Per cent. by weight of water. Saturation.
	1 cc. grams.	1 cu. ft. grams.	
40	1.5900	45.020	20.10
45	1.4575	41.260	22.41
50	1.3250	37.510	27.42
55	1.1925	33.750	31.55
60	1.0600	30.044	36.14
65	0.9175	26.334	41.22

A soil having 40 per cent. by volume of empty space will hold 20.10 per cent. by weight of water when all the space within the soil is filled. A soil having 55 per cent. by volume of empty space will hold 31.55 per cent. by weight of water when all the space within the soil is completely filled.

This amount of empty space in the soil is an important factor in the movement of water through the soil and in the drainage of land.

It will be seen that when the soils are saturated the sandy land has a capacity of only about two-thirds or one-half the amount of water which the clay soils can hold. When these soils are saturated the water may move off through the clay soil more easily and more rapidly, notwithstanding the smaller size of the separate spaces, because the clay soil will hold more water than the sandy land. Where the soils are short of saturation these conditions are reversed, as the size of the separate spaces very largely determines the rate of flow, and the spaces within the sandy land being larger water flows through more readily.

The size of the grains has an important value in determining the amount of empty space within the soil. Most of our soils are of sedimentary origin, or are derived from rocks which are themselves of sedimentary formation. The material out of which the soils are formed has been deposited from suspension in water. The larger the size of the grains the closer the arrangement will be, so that in a coarse sandy soil there will be less empty space than in a fine clay. If cannon balls were poured into a measure and allowed to settle under water they would take up a very close arrangement, because their volume or weight is large in proportion to their surface area, and their weight is sufficient to overcome the resistance of the water and the resistance offered by the adjacent balls. If fine road dust be poured into a similar measure and allowed to settle under water, the volume or weight of the grains is so small in proportion to the surface area that there will be relatively a great amount of friction as the particles descend, so the descent will be extremely slow. Then as the particles touch, the weight of each is not sufficient to overcome the friction against the sides of the adjacent particles and they do not settle into the same compact and close arrangement as the heavier cannon balls, but take up a looser and a lighter arrangement, leaving more empty space. To compact a quantity of this material into a space occupied by an equal weight of the cannon balls would require a very considerable pressure to overcome the resistance offered by the friction between the surfaces of the adjacent grains.

This will account for the large amount of space in clay soils of sedimentary origin, or in clay soils derived from the disintegration of sedimentary rocks; but it is an interesting fact that these same relations hold with soils derived from crystalline rocks. It can hardly be supposed that just 40 per cent. of all such rocks as produce sandy soils have been dissolved out in one case, while 55 or 60 per cent. have been dissolved and leached out of other rocks which give clay soils on disintegration.

It seems much more probable that on disintegration the grains are pushed apart and the volume of material is increased. It must be remembered that in the case of clay soils there is an immense

amount of surface area in proportion to the amount of material, and that any forces that would tend to push the grains apart would have, relatively, great effect. It is very easy to show that there are forces within the soil that would tend to push the grains apart, as is shown in the swelling of clay when wet. It is probable that the tension or potential on the surface separating the soil and water will largely determine how close the grains may come, as in the phenomenon of flocculation already described. If the grains are closer than a certain distance apart there will be this tendency for them to move further apart. It will also be shown in another place that the soil grains are very constantly moving back and forth through the influence of changing climatic conditions, changing water content, and, probably, with changing chemical composition of the soil moisture. It will probably be found that in the disintegration of rocks the fine material swells and occupies a larger volume than before. The finer the material the more surface there is for the forces to act against to keep the grains further apart, and the greater the resistance against their taking up a closer arrangement.

Another property of clay may be mentioned here, due to this function of the small size of the grains. In a symmetrical arrangement of the grains in a soil containing 47.64 per cent. by volume of empty space, each grain will touch the surface of six adjacent grains. There is a certain amount of surface attraction between these particles.

If the grains are large they still only touch at six points, and the weight of the grains is sufficient to overcome this slight surface attraction. A lump of wet sand will fall apart as it dries, for it is bound together by the contracting power of the film of water which surrounds it, and when this is removed by evaporation the weight of the grains is sufficient to overcome the surface attraction of the relatively large and heavy particles, and they fall apart.

If the grains are very small, like grains of clay, the surface attraction of the grains is sufficient to bind the mass into a compact lump when dry; for while there are still only six points of contact for any one grain, there are many more grains and so many more points of contact in a given weight of material. If the size of the grains was still further reduced to molecular proportions the mass would assume the hardness and rigidity of a single grain of sand or clay.

When a dry, compact mass of clay is wet with water the water forces itself in between the grains and forces the grains themselves apart, and the clay swells; but as the grains are held together by their own surface attraction, which is relatively very much greater than with the grains of sand, as well as by the contracting power of the film of water which surrounds them, and as the water keeps them from actual contact and free to move or slide over one another, the mass assumes a plastic condition characteristic of clay when wet. It would seem that

most of the peculiar functions of clay may be explained by purely physical laws, and that they are very largely due to the one function of the small size of the grains. It is probable, therefore, that if quartz could be powdered so fine that the diameter of the grains would come within .005–.0001 millimeter, they would have all the characteristic properties of clay, forming a plastic mass when wet and a hard, compact lump when this wet mass was dried. It would probably absorb water quite as readily as clay does, for it must be understood that this peculiar absorptive property of clay is due to the relatively large extent of surface area and to the extremely small size of the capillary spaces between the grains, and not to any inherent "stickiness" or absorptive power of the grains of clay, which are claimed by some to be porous and to "suck up water as a sponge." The slight film of moisture on the surface of a small watch glass is difficult to get rid of, and is sufficient in quantity to vitiate a careful analysis unless it is always driven off before the glass is weighed. This glass has hardly more than 2 or 3 square centimeters of surface per gram, but if this gram of glass were ground up as fine as the heavy clay of a limestone formation, it may have as much as 5,000 square centimeters of surface area per gram, and each unit of surface may attract as much moisture as before, so that the amount of moisture which the soil can hold when air-dry may amount to several per cent. of the weight of soil.

THE RELATION OF GEOLOGY TO AGRICULTURE.

There are a number of well-marked types of soil in Maryland, some suited to grass and wheat, others to wheat but rather light for grass, others to tobacco, truck, or left out as barren wastes. The texture and general appearance of these soils differ very much, so that one can tell at a glance to what kind of crop each of these types is best adapted. It will be shown that from this difference in texture, which is so very apparent to the eye, there is a marked difference in the relative rate with which water moves within the soil, and the ease with which the proper amount of water may be maintained and supplied to the crop.

As crops differ in the amount of water which they require, and in the amount of moisture in the soil in which they can best develop, this difference in the relation of these soil types to water probably accounts for the local distribution of plants.

In greenhouse culture the same kind of soil is used for all kinds of plants, but great judgment is required in watering the plants. Some plants require a very wet soil, others must be kept quite dry. The amount of water required will not be the same at different stages of development of the plant. During the earlier growing period the soil is kept quite wet, but during the fruiting or flowering period the soil is kept much drier. Each class of plants requires, in this way

special treatment, and it is through this judicious control of the water supply in the soil and the temperature of the air that the best development of each class of plants is attained.

Our soil types, therefore, in having different relations to the circulation of water, partake somewhat of these artificial conditions in greenhouse culture, and on each of them certain classes of plants will find conditions of moisture best suited to their growth and development.

Our soils have been formed from the disintegration, or decay, of rocks. The rocks are made up of different minerals, the most common of which are quartz, feldspar, and mica. The kind of rock is determined by the kind and relative amount of each of these minerals of which it is made. When the rocks decay, part of the minerals, or the cementing material, is dissolved and carried off, and many of the minerals themselves are changed. Now the texture or the relative amount of sand and clay contained in the soil resulting from the disintegration of these rocks, *in situ*, will depend upon the kind of rock, that is, upon the minerals of which it was composed.

The soils of northern-central Maryland have been formed from the disintegration, *in situ*, of the crystalline and semi-crystalline rocks of the Piedmont Plateau.

The material resulting from the disintegration of these rocks is slowly washed away and carried off by streams and rivers. As the current of water becomes slower near the sea the sand is deposited along a rather narrow shore line, while the finer particles of clay are carried further and deposited over wider areas. The conditions where some parts of this material are being deposited may be favorable to the growth of coral and of various kinds of shellfish, so that their remains accumulate in beds of great thickness, giving the material for the limestone of the present day. These sediments are thus assorted out by subsidence in water of different velocities, as though they had been sifted and the different grades of material spread out over wide areas. The soils of southern Maryland and the Eastern Shore are of this unconsolidated sedimentary material, which is still in the first stages of rock formation.

In former geological periods similar sediments, having been slowly deposited in beds of great thickness, were converted into rocks, forming sandstones, limestones, and shales; the sandstone, where the coarser material has been deposited near the shore; the limestone, where the shells have accumulated; and the shales, where the fine mud has been spread out over a wide area of still water.

It is from the disintegration of these "sedimentary" rocks, which have since been raised above the surface of the water and folded into a succession of mountain ranges, that the soils of western Maryland have been formed. There are the limestone valleys, where shellfish were once abundant, and where now is a strong clay soil well adapted

to wheat, composed of what was once the impurities of the limestone rock, which has been left as the more soluble lime has been dissolved and carried away; the sandstone ridges, some of which, resisting decay, form the mountain ranges, while others, made of finer grains of sand and less firmly cemented together, form some of the fertile hill and valley lands; the shales, in which the grains of mud were so extremely small that they have not thoroughly disintegrated in this State, and the soil is filled with fragments of the rock and supports but a scanty mountain pasture.

Geology defines the limits and areas of these different formations and of these different rocks, and as I have shown that these rocks determine the texture of the soil, a thorough and detailed geological map of the state should answer for a soil map. Any one familiar with the texture of the soil, or kind of soil, formed by the disintegration of granite, gabbro, and the different kinds of limestones, sandstones, and shales, should be able to tell by a glance at the map the position and area of each kind of soil. Each color on the map would represent a soil formation which under prevailing climatic conditions would be best adapted to a certain crop.

The wheat, tobacco, truck, and barren lands of southern Maryland are each confined to certain different geological formations for their best development, and a geological map of this portion of the state should show the area and distribution of the lands best adapted to these crops.

There is usually some marked and distinctive botanical character in the herbage of these different soil formations. We have pine barrens, white oak lands, black jack lands, chinquapin lands, grass lands, wheat lands, and truck lands. These names convey a very good impression of the character and texture of the soil, and they should be more generally used. When a soil formation is spoken of as black jack land, the name conveys a distinct impression of the kind of soil, for a soil must have a certain characteristic texture to produce such growth.

SOIL TYPES.

The soils of any wide locality, especially in our Eastern States, appear, at first sight, to offer an endless field of research in the great variety often seen on a single farm and in the same field; but a more comprehensive view of the matter will show this to be due to local causes, which have mixed up and modified the original soil formation. These local modifications may be neglected for the present, until the general features of the representative soils of the region have been worked out. The characteristic properties of great soil formations, or soil types, must first be determined, and then more detailed work may be done in examining soils of local interest.

Why will not truck, tobacco, wheat, and grass grow equally well on all soils? What are the characteristic properties of a good wheat land, of the best tobacco soil, of the best grass land, of the best land for market truck? What is it in the appearance of the soil which enables a farmer to place it in one or the other of these classes? It is not until this problem has been mastered and these very evident differences in the soils have been explained, that the real and full value and application of the chemical determination in plants and soils will be seen. As a rule, the chemical analysis of a soil will not enable a farmer to determine to what his farm is best adapted; but, on the contrary, the farmer, from his experience and judgment, must inform the chemist of this point, and must tell him of the strength and condition of the land.

A large number of samples of soils and subsoils, of representative agricultural value and importance, have been collected in Maryland, and these samples have been classified according to their agricultural value and their geological origin. The soils of all the principal agricultural regions of the state can thus be classified under not more than fifteen different types, and a number of these do not differ materially in their agricultural value, but are given a separate place on account of the distinctive geological formations. The different types will be described when we come to speak of the mechanical analysis of the soils.

THE INTERPRETATION OF THE MECHANICAL ANALYSIS OF SOILS.

THE METHOD.

The method which has been employed for the mechanical analysis of soils is substantially Johnson and Osborn's "beaker method." Twenty grams of the air-dry material were rubbed up in a mortar, with successive quantities of water, and a few drops of ammonia to prevent flocculation, until the liquid on standing a moment became quite clear and the soil remaining in the mortar contained no grains smaller than .05 millimeter, as shown by microscopic measurements. A rubber pestle was used so that the soil grains should not be broken. A very good pestle can be made by putting a rubber cap, such as is used on the ends of chair legs or crutches, over the handle of a porcelain pestle. The coarse material in the mortar was then dried and sifted through a series of sieves with round holes, 2, 1, and .5 millimeters in diameter, and through two pieces of bolting cloth with square holes, having an aperture, respectively, of very nearly .25 and .1 millimeter, the holes being very uniform in size, as shown in the microscopic measurements. The turbid liquid, which was poured off from this coarse material, was allowed to settle until all grains larger than .05 millimeter had settled. The turbid liquid was then poured off and the material in the bottom of the beaker was stirred up with a fresh quantity

of water, and material larger than .05 millimeter was allowed to settle as before. This was repeated until all material finer than .05 millimeter had been removed. The remaining coarse material was thrown in with the "very fine sand." Other separations were made in the turbid liquid, until all grains larger than .005 millimeter were removed, and everything smaller than this was included in the clay group. The turbid liquid containing the last separation was carefully measured in a liter flask, and 100 cubic centimeters of this turbid liquid out of every liter was evaporated to dryness in a porcelain dish. The finest separations, including the silt, fine silt, and clay, were all ignited and cooled in a desiccator before weighing. The coarser grades of sand were not ignited as the amount of moisture which the air-dry material contained was found to be extremely small and within the limit of error of such an analysis. .0001 millimeter is taken as the smallest limit of the clay group, because it is believed that practically all the clay particles are larger than this.

There are, relatively, very wide limits in this clay group, as the largest diameter is fifty times larger than the smallest. This is of very great importance, as the extremely small size of the grains gives a very large number of grains for a given weight of material, and the aggregate extent of surface area of this vast number of particles is usually larger than of all the other grades combined. It would be very desirable to have a greater number of separations, an infinite number if this were possible, so as to have very narrow limits between the diameters and so that the diameters of all the particles in a single separation shall be very nearly of the same size. It is practically impossible, however, with this beaker method to make more than the number of separations which have been adopted, as it takes a long while to make the separations. This clay group is of so much importance, therefore, that a very slight difference in the value of the diameters will give widely different absolute values in the determination. It is impossible, however, to expect that the absolute number of grains in one gram of soil could ever be determined, and if they could be, the science of mathematics is not refined enough to deal with them as we wish. Comparative results can alone be expected, and one of the essential things in this is to have the mechanical analysis made by methods which give fairly uniform results, while the number and value of the separations, and especially of this clay group, be always the same.

In the mechanical analysis, when any of the separations were allowed to remain some time to settle out, the material in the bottom of the beaker was rubbed up in the mortar with a rubber pestle, as it was liable to cake on standing.

APPROXIMATE NUMBER OF GRAINS IN ONE GRAM OF SOIL.

Having determined the amount of empty space in the soil by a

method already given, it is important to know how much this space has been subdivided. There is about half a cubic foot of empty space in a cubic foot of soil, and it is evident that if this space formed one large cylinder a large body of water would flow through with great rapidity. It is also evident that water will flow through this space more and more slowly the more it is subdivided. The amount of subdivision of the space will depend upon the number of grains in the soil, and somewhat upon their arrangement. The approximate number of grains per gram can be calculated from the mechanical analysis of the soil by the following formula:

$$\frac{a}{\frac{\pi\,(d)^3\,\omega}{6}} \div A$$

Where a is the weight of each group of particles, d, the mean diameter of the particles in the several groups, A is the total weight of soil, and ω is the specific gravity of the soil.

In using the formula the per cents are used as grams, thus, if there were 20 per cent. of silt this would be taken as 20 grams, and if the results of the analysis added up 97 per cent. the whole weight of soil would be taken as 97 grams. The diameter (d) is taken as the mean of the extreme diameters given for any group. For instance, for the silt this would be .03, which is assumed to be the diameter of the average sized particle.

The specific gravity has been taken as 2.65 in all the determinations which have been made. This value was originally selected from a statement by Johnson, in "How Crops Feed," page 159, of some determinations by Schöne, and our own results have shown no very good reason for changing this unless the value 2.70 be substituted, or unless the specific gravity of each soil be specially determined for insertion in the formula, which hardly seems necessary at the present stage of the investigation.

The following table gives the specific gravity of some of our type subsoils, the type sample being made up in most cases of samples from a number of localities:

Specific gravity of type subsoils.

No.	Soil.	Air-dry.	Ignited.
276	Pine barrens	2.6388	2.6485
284	Truck	2.6259	2.7016
286	Tobacco	2.6151	2.7100
290	Oriskany	2.6550	2.6583
280	Wheat	2.5949	2.7109
278	River terrace	2.6229	2.6855
181	Triassic red sandstone	2.7115	2.7759
238	Catskill	2.6875	2.7201
289	Shales	2.6625	2.7302
288	Helderberg limestone	2.6978	2.7385
	Average	2.6512	2.7079

Specific gravity of separations.

Diameter.	Conventional names.	Specific gravity.
mm.		
2–1	Gravel	2.6469
1–.5	Coarse sand	2.6547
.5–.25	Medium sand	2.6476
.25–.1	Fine sand	2.6594
.1–.05	Very fine sand	2.6807
.05–.01	Silt	2.7337
.01–.005	Fine silt	2.6642
.005–.0001	Clay	2.8368

The specific gravity of the silt and clay groups in the list of separations is quite high, and the duplicate results, of which the mean is given, were rather wide, for what reason has not yet been determined, unless it is due to chemical changes of the iron compounds in the ignition of the material.

It must be remembered that the results obtained by the use of this formula of the number of grains per gram have only approximate values, and can only be used in comparative work.

The approximate number of grains per gram will be given with the results of the mechanical analysis of the soils. One table will be given in detail, showing the approximate number of grains in each separation in one gram of subsoil, from which it will be seen that the extremely small diameter assigned to the clay group has an important value, as the vast number of grains in this and in the fine silt practically determines the number of grains per gram.

THE ESTIMATION OF SURFACE AREA OF SOIL PARTICLES.

The approximate extent of surface area of the soil grains in one gram of soil can be calculated from the foregoing by the following formula:

$$\pi (d)^2 n$$

in which d is the mean of the diameters of any group in centimeters, and n is the number of particles in the group.

The following logarithmic constants have been used in the calculation of the results, using 2.65 in all cases as the specific gravity of the soil:

Diameter. (d)	Approximate number of grains. (log.) $\frac{\pi (d)^3 w}{6}$	Surface area. log. $(d)^2 \pi$
cm.		
·15	$\bar{3}$·6703	$\bar{2}$·8493
·075	$\bar{4}$·7674	$\bar{2}$·2473
·0375	$\bar{5}$·8641	$\bar{3}$·6451
·0175	$\bar{6}$·8711	$\bar{4}$·9831
·0075	$\bar{7}$·7674	$\bar{4}$·2473
·003	$\bar{8}$·5734	$\bar{5}$·4513
·00075	$\overline{10}$·7674	$\bar{6}$·2473
·000255	$\overline{11}$·3616	$\bar{7}$·3101

CALCULATION OF THE RELATIVE RATE OF MOVEMENT OF WATER THROUGH SOILS.

It has been stated that the relative rate of movement of water through soils will depend upon how much space there is in the soil; upon how much this space is subdivided, *i. e.*, upon how many grains of sand and clay there are in the soil; upon how these grains are arranged, and upon how this skeleton structure is filled in and modified by organic matter.

It will be assumed for the present that the grains have the same mean arrangement in all the soils and the influence of the organic matter will be assumed to have the same value in all cases, and this will also be neglected for the present. Where the rate calculated from the mechanical analysis of the soil differs from the observed rate determined experimentally, it may be assumed that the grains have a different mean arrangement in the two soils or that the influence of the organic matter is not the same.

There will evidently be one space, or opening, into the soil for every surface grain, and the approximate number of grains, or of openings, on a unit area of surface may be found by the following formula:

$$N = \left(\sqrt{\frac{M \times W}{V}}\right)^{2/3}$$

Where N is the number of grains, or openings, on one square centimeter of surface, M is the approximate number of grains in one gram of soil, W is the weight of soil, V is the total volume of the soil grains and the empty space.

If the grains are assumed to be symmetrically arranged and the

spaces between them cylindrical in form, the radii of the spaces can be found by the following formula:

$$r = \sqrt{\frac{V_1}{\pi N L}}$$

Where r is the radius of a single space, V_1 is the total volume of the empty space, N is the number of grains or spaces on one square centimeter of surface, and L is the depth of the soil.

If the space within the soil is completely filled with water the relative rate of flow of water through the soil will be according to the fourth power of the radius of a single space multiplied by the number of spaces on the unit area of surface, as shown by the following formula:

$$T_1 = \frac{N\,(r)^4\,T}{N_1\,(r_1)^4}$$

Where N–N_1 are the number of spaces, and r–r_1 are the radii of single spaces in the respective soils, and T–T_1 the time required for a unit volume of water to flow through the soils under the same head or pressure.

The space within the soil is rarely filled with water in agricultural lands, but the most favorable amount of water for the soil to hold, as Hellriegel and others have shown, is from 30 to 50 per cent. of the total amount of water the soil could hold if all the space within it were filled.

If the space within the soil is only partly filled with water, as in most arable lands, the water will move in a thin film surrounding the soil grains and according to the fourth power of the thickness of the film. The mean thickness of the film surrounding the soil grains may be theoretically determined by the following formula, which is based on the conception that the film is cylindrical and of uniform size throughout:

$$t = r\left(1 - \sqrt{\frac{s}{s+p}}\right)$$

Where s is the per cent. by weight of water which the soil will hold when the empty space is filled with water, p the per cent. of water actually contained in the soil, r the radius of a single space, and t the mean thickness of the film surrounding the soil grains.

The relative rate of flow of water through the soils will then be according to the following formula:

$$T_1 = \frac{N\,(t)^4\,T}{N_1\,(t_1)^4}$$

It must be remembered that these formulæ give only approximate and comparative values for comparing one soil with another. The structure of the soil is altogether too intricate to expect ever to obtain absolute values.

DETERMINATION OF THE ACTUAL RATE OF FLOW OF WATER THROUGH SOILS.

A method has been given, based on theoretical considerations, for the calculation of the relative rate of movement of water through soils from the mechanical analysis. The following method has been used to determine the actual rate of flow of water through the soil in its natural position in the field, and described in the Experiment Station Record, volume 3, No. 10 (May, 1892), page 68.

To determine the actual rate of circulation of water in the soil or subsoil in its natural position in the field, a hole should be dug, and the soil and subsoil on one side removed to the depth at which the observations are to be made. A column of the soil or subsoil, 2 inches or more square, and 4 or 5 inches deep, is then to be carved out, and a glass or metal frame, a little larger than this and 3 or 4 inches deep, is slipped over the column, and melted paraffine is then run in to fill up the space between the soil and the frame. The soil is then struck off even with the top and bottom of the frame, a piece of linen tied over the under side, or what is better, the frame can rest on some coarse sand or gravel, contained in a funnel, to prevent the soil from falling out and to provide good drainage for the water to pass through. A section of the frame can then be placed on the top and secured by a wide rubber band, or otherwise, and the time noted which is required for a quantity of water to pass through the saturated soil. The initial depth of water over the soil must be the same in all the experiments. Root-holes and worm-holes are to be avoided, and these are particularly troublesome in clay lands. The amount of space should be determined in this or in another sample, as described in a previous section.

These determinations are usually made out in the field. They are rather troublesome to make, especially as most of them have to be made in different parts of the state, and they require considerable time; only a few of these determinations have been made in the soils of Maryland as most of our time has necessarily been occupied in the preliminary work of securing samples from as many widely separated localities as possible, and making the mechanical analysis of the same to give material and data to work on. With this in hand the field has all to be gone over again, to study the texture of the soil and the arrangement of the soil grains, and this will involve the determination of the actual rate of flow of water through the soils in their natural position in the field. The preliminary work had to be done first so that this work would have a meaning. The actual determinations which have been made will be given with the mechanical analysis of the soils.

Considerable work has been done on the flow of water through air-dried soils, loaded into tubes. Eight-inch Argand lamp chimneys are

used, with a piece of muslin tied tightly over one end. A mark is placed on the side of the tube 6 inches above the lower end. The chimneys are about 2 inches in diameter, and the capacity of the tube up to the 6-inch mark is about 300 cubic centimeters. The tube is filled with 6 inches in depth of soil by gently tapping the bottom of the tube. The tube is weighed before and after the soil is introduced, when the weight and volume of the soil and the volume of the empty space may easily be calculated if the specific gravity of the soil is known. 2.65 has, in all cases, been used as the specific gravity of the soil. From this data and the mechanical analysis of the soil the relative rate with which water will move through the soil can be calculated.

The soil should then be saturated with water and the tube supported so that the muslin just touches the surface of the water, contained in a vessel below, to reduce any tension at the bottom of the soil. What is better than this is to remove the muslin from the bottom of the tube before the soil is saturated, and place the tube on some fine gravel or coarse sand, contained in a funnel, to keep the soil from falling out, but to provide good drainage for the water. When the soil is saturated and water is flowing from the funnel, an inch in depth of water (41 cubic centimeters) is then carefully poured on the soil and the time noted that is required for it to pass through the soil, or to displace an equal quantity of water from the tube. The initial depth of water in these determinations is $1\frac{1}{2}$ inches, and the time is noted which is required for the water to fall one inch, or to within $\frac{1}{2}$ an inch of the surface of the soil.

It is extremely difficult to fill these tubes in this way with air-dry soil without a separation of the finer particles into separate layers, which would retard the flow of water. The tubes often have to be filled several times before they are uniform in appearance. In view of this difficulty, it is much better to slightly moisten the soil before filling into the tube. But as the amount of moisture affects the arrangement of the grains and the rate of flow, we have used 3 per cent. of moisture in all cases. To mix this uniformly and easily with the soil, rather more than the requisite quantity is poured on to the soil and covered over with the dry material and let stand for a number of hours to soak in. After this it can be thoroughly and easily mixed by hand without the formation of lumps. After thorough mixing it is allowed to stand, if necessary, until the soil contains only 3 per cent. of water, and it is then thoroughly mixed again and loaded into the tube.

This method is not so reliable as where the soil is taken in its natural position in the field, for the effect of drying and the necessary preparation of breaking down the lumps which have been formed in drying, before loading into the tube, may very materially modify the arrangement of the soil grains. Still, when it is remem-

bered, that in plowing the soil is turned over and allowed to fall back as it would fall into the tube and is often quite completely dried out during this process, and that this does not very materially change the arrangement of the soil grains if done intelligently, perhaps these objections are not as serious as they would appéar at first sight, and that soil samples brought from a distance can be compared in this way. It would be very desirable if a method could be devised for determining the actual rate of flow of water through soils short of saturation, when they contained, say, 8 or 10 per cent. of moisture.

There is another difficulty encountered in this method, that where the saturated soils are left standing the rate of flow becomes slower and slower, probably caused by a rearrangement of the soil grains, due to the repeated quantities of water changing the composition of the soil moisture. For this reason it is better to pass air through the soil than the denser fluid water. A known quantity of air can be passed through the soil at a definite pressure and the time noted, as in the case of water. This is a much more satisfactory method, as there are no chemical or physical changes to be feared.

THE RELATION OF SOILS TO WATER.

The samples which are to be described have all been very carefully collected by the writer. The early sampling was done with a spade, but most of the Maryland soils have been collected with a 2-inch wood auger, one end being fitted for a small iron pipe which could be inserted at will for a handle. The auger can readily sample to a depth of 18 inches from the surface, and besides the much greater convenience in carrying and in sampling over the spade, it brings up a complete sample to the desired depth, the whole of which is carried to the laboratory, and it is not necessary to mix it in the field to select a small sub-sample, as must be done when the spade is used.

The sample of soil is taken down to the change of color, or, when this is not apparent, to a depth of 6 inches, and the subsoil is taken from below this to a depth dependent upon the nature of the material, but usually to a depth of 18 inches from the surface.

The subsoil alone has been analyzed and examined in most cases, for the soil has been subjected to artificial conditions and manuring, which might materially modify the results of the investigation, and besides, the undisturbed subsoil practically determines the movement of water, and it is the subsoil, rather than the soil, upon which the practical farmer bases his judgment of the strength and character of the land.

The samples have been taken from as widely different localities as possible, and from many different soil formations, and they are accompanied, as far as possible, with very full notes on their geological

origin, their agricultural value and importance, and to a lesser degree upon the botanical character of the natural growth. Some of these samples have been quite fully described in the Fourth Annual Report of the Maryland Agricultural Experiment Station, but only such peculiarities will be mentioned here as may seem necessary or desirable in the presentation of the results.

SOUTH CAROLINA SOILS.

Some very interesting conditions were presented in the study of the South Carolina soils, which throw light on the subject under consideration, and which show very plainly the relation of the texture and of the physical properties and condition of the soil to the local distribution of crops.

The conditions most favorable to the production of cotton may be briefly stated as follows: From the time of planting, the temperature and rainfall gradually increase until about the middle of July or the first of August, when the plant has practically attained its growth and has laid up all the food material needed for a full crop. During this growing period an even temperature is desired, with a high temperature as the plant attains good size. Plenty of sunshine is needed, and frequent rather than long continued showers. The ground is thoroughly cultivated and the crop is kept free of weeds and grass to conserve the moisture in the soil. The conditions which prevail are nearly tropical, and if they continued the plant would continue to grow as a perennial shrub with little tendency to ripen fruit. But after the first of August the temperature rapidly falls, there is less rainfall, cultivation is stopped, and the soil becomes cooler and drier, the real growth of the plant is checked, and the food material stored up by the plant is transferred to the fruit, and the plant ripens up a crop.

The *lower pine belt* in South Carolina covers nearly one-third of the state, but produces only about 5 per cent. of the cotton crop of the state. The soils are fair and the meteorological conditions must be favorable, for on one side of this belt are the fertile Sea Island cotton soils along the coast; on the other side is the fertile "red hill" formation, which contains some of the finest upland cotton lands of the state. The land in this lower pine belt is everywhere very level and very low, so that there is poor drainage, the water often rising to within a foot of the surface in the wells, and, indeed, covering much of the country between the water courses, as it can neither flow off the level surface nor down through the already saturated subsoil.

On what are called the "ridge-lands," bordering the water courses, and for two or three miles inland from the principal rivers, which have worn their way down in the soft material for 50 or 100 feet, the soils have good drainage, and very large crops of cotton are produced, while

further away from the water courses the land is almost entirely left out in forest growth. Probably much could be done with this land with improved methods of cultivation and by judicious manuring, but the land needs underdrainage, and it would be both difficult and expensive to get good drainage in this low, flat country. Where cotton is cultivated there are all the signs of too moist a soil. The plant attains a large size, and one would suppose it would supply a large yield, but it puts on little fruit, hardly more than a third of what would be expected from the size of the plant, and much of this is lost by rust and shedding. The growth of the plant is not properly checked, and when a change does come it is sudden and severe, and lowers the vitality of the plant, rendering it liable to disease and insect ravages.

The texture of these soils and the relation to moisture undoubtedly determine the low yield of crop. The most important thing which could be done in the improvement of these lands would be the introduction of a system of under-drains, but even without this it would undoubtedly be possible to introduce improved methods of cultivation and manuring which would check this excessive growth, and induce the plant to ripen up a larger crop.

THE SEA ISLAND SOILS.

Very interesting conditions, showing the influence of soil moisture on the local distribution of crops, are seen on the Sea Islands off the coast of South Carolina. The soils of the Sea Islands consist generally of a very fine sand, the particles of which are of very uniform size, as shown by the mechanical analysis. The soils are naturally rather poor but are capable of a high state of cultivation. The natural growth is oak, hickory, gum, and chinquapin. There is no original pine, but fields left out grow up in old field pine. James Island, just across from Charleston, and one of the most northern of the the Sea Islands, and to which these notes have more particular reference, is some 8 or 9 miles long and from 2 to 3 miles broad. The soil on the south side is generally "sandy," with a sandy subsoil down to water level, which is from 5 to 6 feet below the surface. On the north side of the island or that nearest to the mainland, there is a yellow clay or loam subsoil. The surface of the water in the wells is generally 5 or 6 feet below the surface of the ground, and is quite fresh even if the well is near the shore. If the well is much deeper than this, however, the water is salt, even in the center of the island. This is in accordance with a statement made by Storer of conditions prevailing near Boston.

When the Sea Island cotton was first introduced into South Carolina, about 100 years ago, it failed to mature before frost, and for this reason the first crop was lost. The crop ripens now very much earlier

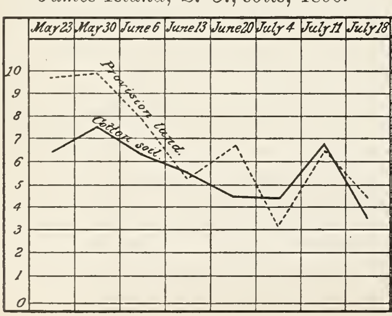
so that there is no danger from frost. The planters have evolved a very peculiar system of cultivation, the plants are grown on very high beds or ridges from 12 to 18 inches high, and from 4 to 5 feet broad, partaking somewhat of the nature of the ridges used by the Romans, and for the same reason, *i. e.*, to keep the roots of the plant in thoroughly drained and comparatively dry soil. The subsoil is never disturbed and soft mud from the adjacent marshes and salt marsh grass and litter of all kinds are placed in the bottom of the bed, effectually keeping the roots from developing down into the moist subsoil. The bed itself is very highly manured. During the last twenty years the finest cotton lands have been gradually underdrained with tile drains, costing from $10 to $60 per acre, depending on the character of the land and the distance apart of the tiles. The sandy lands have only to be drained in low places, while in the heavier soils drains are placed from 25 to 100 feet apart and from 2 to 4 feet deep, with a fall of about 5 inches in 100 feet where possible. The planters believe that underdrainage has made the crop much earlier and surer and that the high beds are not now as necessary as formerly. They are able to maintain any grade of cotton desired by judicious cultivation and careful selection of seed.

The finest cotton lands are near the water, where the lands are better drained than in the interior. These lands are given up entirely to Sea Island cotton, and of recent years to early truck and vegetables for northern markets. The land in the interior of the island is not so well drained and does not yield as productive crops of cotton, nor as fine staple, as the crop is generally more liable to shedding, flagging, rust, and insect ravages than on the better drained soils just described; this land is better for corn than the finest cotton soils, and it is generally known as "corn" or "provision land," as it is given up to the cultivation of corn and provisions for the farm.

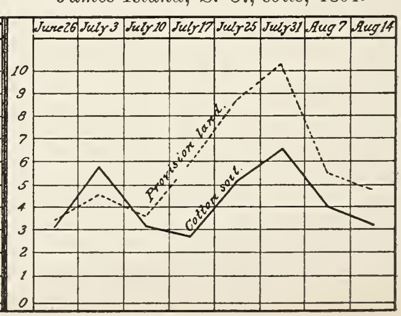
Cotton usually starts out well on this land and the plants attain a large size but put on very little fruit and are liable to disease and insect ravages.

The following diagrams show the moisture curve in two soils from James Island, S. C. Both soils were in cotton and samples of the

James Island, S. C., soils, 1890.



James Island, S. C., soils, 1891.



soil were taken weekly for the moisture determination. The sample was taken with an iron tube 9 inches long and 2 inches in diameter, which was driven down its whole length into the soil. The sample was sent to the station in air-tight glass jars, and the moisture was determined by air-drying about 1,000 grams of the material.

The time covered only a part of the growing period of the crop each year. In 1890 this was of the early part of the season, and in 1891 of the middle and latter part of the true growing season before the ripening period really commenced.

It will be seen that the moisture curve for the provision land is very much more irregular than that for the cotton soil, and it is undoubtedly these marked and sudden changes which render the crop less certain. On July 25, 1891, rust appeared in the cotton on the provision land, and by September 4th the plants had lost nearly all their leaves from this cause.

The planters themselves believe that underdrainage and high beds, with heavy applications of salt mud to keep the roots from developing down into the subsoil, will check the growth of the plant and enable as good crops to be grown here as elsewhere, but as these lands are inland, both the mud and drainage are costly and difficult to apply.

The mechanical analyses of some of the soils from James Island are given in the accompanying table, including three principal types of Sea Island cotton lands and one sample of the "provision" land from the interior, on which cotton cannot be economically produced. The approximate extent of surface area, in square centimeters per gram, and the approximate number of grains per gram, are also given as calculated by the formulæ already given. The results cannot be compared directly with the work on the Maryland soils for there are not so many separations, and the absolute values are not the same.

Mechanical analyses of Sea Island cotton subsoils from James Island, S. C.

Diameter.	Conventional names.	Sea Island cotton lands.			
		82.	84.	86.	88.
		Clay land.	"Sand and gravel."	Sandy land.	Provision land.
mm.					
2–1	Fine gravel	0.00	0.59	0.00	0.00
1–.5	Coarse sand	0.54	3.67	0.00	0.88
.5–.25	Medium sand	1.03	4.27	0.67	2.50
.25–.05	Fine sand*	83.20	78.88	90.14	82.97
.05–.01	Silt	6.44	4.20	3.35	6.30
.01–0	Clay†	7.17	6.63	4.78	5.70
	Total	98.38	98.24	98.94	98.35
Organic matter, water, loss		1.62	1.76	1.06	1.65

Mechanical analyses—Continued.

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
86	Sandy land	4.78	383.7	279,000,000
88	Provision land	5.70	441.9	336,000,000
84	Sand and gravel	6.63	464.8	390,000,000
82	Clay land	7.17	509.7	421,000,000

* Including "very fine sand" of later analyses (.1-.05 millimeter).
† Including "fine silt" of later analyses (.01-.005 millimeter).

The "provision" land need hardly be considered here, for the trouble with the land is admitted to be poor drainage, owing to its location; and in many cases it has a layer of iron ore underlying it at a depth of 3 or 4 feet from the surface.

Of the cotton soils the clay land (82) is considered the strongest soil. With the same treatment it produces a larger yield per acre, although the fiber is rather shorter and heavier, than the sandy land. The Sea Island planters have an admirable method of selecting seed and they can maintain almost any desired grade of lint. They select the sandy land (86), however, in preference to the clay land for the finest grade of lint. With the same seed and treatment the sandy land does not produce so much yield per acre as the heavier clay land; the plants moreover are not so large, the crop ripens earlier, and the lint is somewhat finer and longer. The agricultural value of these cotton soils varies with the amount of clay they contain and with the approximate number of grains per gram, as given in the table, and the planters realize that the sandy soils are less retentive of moisture and are, as a rule, drier, and that it is this fact, rather than lack of plant food, which explains the difference in their agricultural value.

THE WEDGEFIELD SOILS.

Very interesting conditions have also been studied in three soils from Wedgefield, S. C. Wedgefield is situated on a narrow strip of the "red hill" formation, about 2 miles from the Wateree River, and the railroad station is about 150 feet above low water, with a bold bluff coming down to the swamp, about half way between the station and the river. The soil of this red hill formation has a strong, dark red clay-loam subsoil. The formation widens out considerably in Orangeburgh and Aiken counties, and is noted throughout its whole extent for its fertility and the excellent conditions for a good cotton soil. The land is gently undulating, with good surface drainage, and, although a compact red clay from 40 to 80 feet thick, it has good underdrainage. It is considered a very safe soil, as cotton rarely suffers from excessive wet or dry weather and the plants are usually very vigorous and are not subject to rust, shedding, or lice, as on the adjacent lands. With good treatment it may be relied on to produce 1,000 to 1,400 pounds of seed cotton. If anything, the soil is consid-

ered rather too close and too retentive of moisture, and this, together with rather high nitrogenous manuring, has inclined the plant on this particular soil to make rather an excessive growth for the amount of fruit which it produces. On the whole, the soil of this formation is considered the finest type of upland cotton soil in the state. The wells are usually about 40 feet deep, but are often 80 feet and even 120 to 160 feet deep.

About 1¾ miles from the station at Wedgefield, there is a range of sand hills bordering the red hill formation and extending for miles up and down the river. The soil and subsoil are coarse, yellow sand, with red clay fully 15 to 20 feet below the surface, on the plateau where these samples were taken just before entering the sand hills proper. Cotton cannot be economically produced on this land, for the soil is so light in texture that the crop suffers in excessive wet or dry weather. With the same treatment it is thought that it will not make one-fifth as much cotton per acre as the "red land." The sandy land makes fairly good crops of corn and is excellent for sweet potatoes, melons, and early truck. It is never planted in cotton by the large planters.

There is a narrow belt, about ½ mile wide at this place, lying between the red hill formation and the sand hills, locally known as "gummy land," because, although it appears to be a coarse, red sand, it gums up and sticks to a plow, especially when it is quite moist. In color it is precisely like the red land, and the mechanical analysis shows that it contains about the same amount of clay. In texture it looks and feels like red sand. In its relation to moisture, also, it behaves more as a sand than as a clay, so that crops suffer in excessive wet or dry seasons. In unfavorable seasons the plants are small and the vitality of the plants is so much lowered that they are rendered liable to disease and insect ravages. In a good season and with the same manuring and treatment it is thought that this land will make only about four-fifths as much crop as the red land, but in unfavorable seasons the difference is much greater than this.

No amount of fertilizers, as usually applied, will make these two soils as productive or as safe for cotton as the red land. The meteorological conditions are the same over all, and the difference is undoubtedly due to the physical properties of the soils, and especially their relation to water, rather than to any difference in chemical composition. The planters themselves freely admit that the peculiarity of these soils and their natural or acquired fertility are largely dependent on their relation to the moisture supply of crops.

The mechanical analyses of these soils are given in the accompanying table, with the approximate number of grains per gram and the approximate extent of surface area of these grains in square centimeters per gram.

Mechanical analyses of subsoils from Wedgefield, S. C.

Diameter.	Conventional names.	74. Red land.	76. "Gummy" land.	78. Sandy land.
mm.				
2–1	Fine gravel	1.11	1.98	2.88
1–.5	Coarse sand	5.92	14.91	31.45
.5–.25	Medium sand	9.67	20.17	27.31
.25–.05	Fine sand*	42.75	25.47	28.14
.05–.01	Silt	7.54	6.92	3.96
.01–0	Clay†	28.85	26.25	3.97
	Total	95.84	95.70	98.68
Organic matter, water, loss		4.16	4.30	1.32

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
78	Sandy land	3.97	284.8	232,700,000
76	Gummy land	26.25	1,358.0	1,587,000,000
74	Red land	28.85	1,496.0	1,736,000,000

* Including "very fine sand" of later analyses (.1–.05 millimeter).
† Including "fine silt" of later analyses (.01–.005 millimeter).

The amount of empty space in these lands is given in a preceding table, and it will be seen from this table that this space is divided more in the red land than in the sandy land, as there are a great many more grains in the former than in the latter. Experiments were tried with the air-dried soils in the laboratory to determine the relation of these soils to water and especially the ease with which water would move through them.

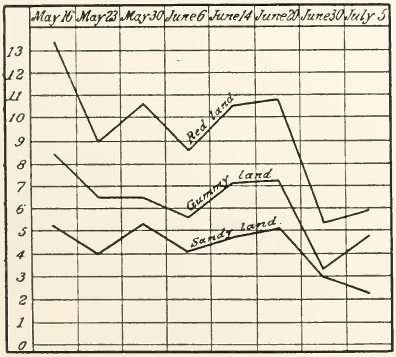
A quantity of the red land was loaded into a tube, the amount of space being determined in the way already described. An inch in depth of water (41 cubic centimeters) passed through the saturated subsoil in 133 minutes. As this soil is considered rather close and retentive of moisture, making the crop rather late in starting off and growing rather late in the fall, a number of fertilizing materials were applied to diminish the rate of flow. A few drops of a saturated solution of gypsum made the water pass in 105 minutes, as a result of several trials.

Taking 133 minutes for the red land as a basis of calculation, the same quantity of water should pass through the same depth of sandy land of a given compactness and as calculated from the mechanical analysis in $5\frac{1}{2}$ minutes. The water actually passed through in $3\frac{3}{4}$ minutes, a result agreeing very closely with the calculated time. The "gummy land" contains very nearly as much clay and very nearly as many grains per gram as the red land, and it was calculated from the mechanical analysis that the same quantity of water should pass through this subsoil, as loaded in the tube, in 130 minutes. The water actually passed through in 14 and 16 minutes, as a result of several trials. The soil appears like a sandy soil. The mechanical

analysis shows that it contains only about the same amount of the different grades of sand as the red land, but it has rather more of the coarser grades. It appears as though the clay were held closely to the grains of sand, through flocculation perhaps, giving the appearance of larger grains than the soil really contains. In the mechanical analysis of the material flocculation was so troublesome that ammonia had to be used to overcome and prevent it, as the clay liquid would settle out clearly and at once without this addition. A few drops of ammonia were, therefore, added to the water as it was passing through the subsoil in the tube, and it checked the rate of flow *at once*, so that it took over 2,000 minutes for the liquid to pass. The alkali was evidently stronger than it should have been, as it made the soil almost impervious to water. The action of the alkali on the soil could be traced as it proceeded down the tube, the soil appearing to slake and the grains of clay to fall away from the grains of sand. The action could be distinctly watched through a microscope focused against the inside of the tube. The fine silt and clay particles could be seen to leave the grains of sand and gather in loose light flocks in the spaces within the soil.

There seems no doubt but that the trouble with this soil was in the arrangement of the soil grains, in which the clay particles did not have their best effect in retarding the rate of flow and in making the soil sufficiently retentive of moisture. The grains were probably so arranged that some of the spaces within the soil were relatively extremely large. The ammonia changed this and caused a rearrangement of the soil grains by which they were more evenly distributed throughout the soil. It is probable that other substances would have had the same effect, and that through their judicious use the grains of clay could have been pushed a little further apart, and the soil be made as retentive of moisture as the red land and as productive and as safe a soil for cotton. This is the line in which the improvement of this land should be worked out. There is sufficient clay in the land to make it as retentive of moisture as is required in the best cotton soil, and to improve the land the object should be to push these grains of clay apart so as to change the texture of the soil.

Diagram showing the percentage of moisture in the Wedgefield soils.



Samples were taken from each of these three soils once a week during a portion of the season of 1890, and moisture determinations were made by air-drying the soils. The samples were taken to a depth of 9 inches from the surface. The

preceding diagram shows the amount of moisture in the soils at the stated times.

It is to be observed that the season, as a whole, was too wet for the best development of the crop. On the red land this resulted in rather too much growth and too little fruit in proportion to the size of the plants, but the plants themselves were otherwise vigorous and healthy. On the "gummy land" and sandy land, however, the vitality of the plants was seriously impaired by the frequent and heavy rainstorms; the plants were small and were very seriously injured by lice. It happened that the rain came in very heavy and soaking storms, almost invariably three or four days before the samples were taken, and this was followed by a succession of hot, sunny days, so that the diagram does not give a true idea of the moisture in the soils, as it would if the rainfall had been more evenly distributed, or if the samples had been taken at more frequent intervals. The difference in the moisture content of these soils, as shown by the diagram, is probably amply sufficient to account for the difference in the agricultural value of the lands. When it is considered, also, that this was an unusually wet season, the amount of moisture which can be maintained for the crop by the sandy land in an average season must be very small. It is unfortunate that these records could only be extended over part of a single season.

One cannot help but think that the difference in the agricultural value of these three soils is due to the relation of the soils to water, and the amount of water which they can maintain for the crops, and that this factor, alone, determines the local distribution of crops and makes it evident why melons and sweet potatoes are admirably adapted to the "light lands," and cotton to the heavy clay or loam soils.

If it is conceded that this is the trouble with the "gummy land" it will be comparatively a simple matter to work out methods of treatment or fertilization which will overcome this trouble. It would be much easier to improve the land in this direction and to force the grains further apart than it would be to draw the grains more closely together in the impervious Potomac clays of Maryland, and make them more loamy and less retentive of moisture. It must be recognized, however, that this physical condition of the soil is the controlling cause in crop production and that any fertilization is not, or should not be, primarily, to supply plant food to the soil but to act in changing the physical structure of the land. The "best fertilizer" for this land may have little or no commercial value, or it may be any one of the high grade commercial fertilizers.

Many other interesting problems, showing the effect of the texture of the soil and the relation to water on the distribution of crops, could be given as presented by the South Carolina soils and in the cultiva-

tion of the cotton crop. Cotton is as sensitive to these conditions of heat and moisture as many greenhouse plants, and responds readily and quickly to changes in these conditions. If the season or soil is too wet, the plants are inclined to excessive growth and put on but little fruit; if too dry, the plants do not attain sufficient size but put on generally more fruit in proportion to the size of the plant and the amount of food material which has been stored up. Sudden changes of moisture or temperature lower the vitality of the plant and render it liable to disease and insect ravages. The plant is peculiarly sensitive to these physical conditions and is admirably adapted to these soil investigations.

It is to be regretted that this work could not have continued in South Carolina as the point had just been reached where a large amount of material and data had been collected to work with, but the work was, unfortunately, broken up.

MARYLAND SOILS.

We come now to speak of some problems presented by the soils of Maryland, where, it will be understood, much time has been spent in necessary preliminary work in collecting material and data. We have also to leave the study of cotton, which is so extremely sensitive to its environments, and take up the study of wheat, which is not very sensitive but which, on the contrary, readily adapts itself to marked changes in its environments, as seen in the very wide and general distribution of the plant throughout the world.

The average yield of wheat per acre for each county in Maryland, as calculated from the returns of the tenth census, is as follows:

Average yield of wheat per acre, as given in the tenth census.

	Bushels.
Southern Maryland:	
Charles	7.1
Calvert	7.6
Saint Marys	8.3
Anne Arundel	9.0
Prince George	9.0
Average	8.2
Eastern Shore:	
Worcester	7.1
Wicomico	7.2
Dorchester	7.6
Caroline	10.2
Somerset	10.3
Queen Anne	13.5
Talbott	14.1
Kent	14.8
Average	10.6

Average yield of wheat per acre—Continued.

Northern and Western Maryland:	
Allegany	8. 9
Garrett	10. 7
Baltimore	13. 7
Carroll	14. 4
Cecil	15. 7
Howard	16. 5
Harford	16. 7
Montgomery	16. 9
Frederick	16. 9
Washington	18. 0
Average	14. 8

The state of Maryland contains approximately 10,000 square miles of land surface. It is divided geographically into four sections: Southern Maryland, having an area of approximately 2,000 square miles, has gently rolling country, and forms a peninsula with the Chesapeake Bay on the east and the Potomac River on the south and west. The Eastern Shore, containing approximately 3,000 square miles with generally level surface, having the Chesapeake Bay on the west, the Atlantic Ocean and the state of Delaware on the east, and two counties in Virginia on the south. Northern and western Maryland contain together approximately 5,000 square miles, and may be classed together here for the following study. The surface is quite rolling in northern Maryland and mountainous in western Maryland.

The largest average yield of wheat per acre, as given in the above table, is 18 bushels in Washington county. This is principally from the heavy clay lands of the Trenton chazy limestone formation of the Cumberland Valley. The lowest average yield per acre is in the lower counties on the Eastern Shore and southern Maryland. The soil on the lower part of both of these peninsulas is notoriously light and sandy. The Eastern Shore and southern Maryland belong to the Coastal Plain, and have the undisturbed and unconsolidated strata from the Jurassic to the present time. Northern-central Maryland belongs to the Piedmont Plateau, made up of the highly crystalline rocks towards the east, and semi-crystalline towards the west. Western Maryland contains the entire sequence of Paleozoic strata, in several series of folds or undulations. The geology of the Eastern Shore has not yet been worked out in any detail, and there has been no attempt to examine or classify the soils.

The soils of southern Maryland are generally light in character and texture, ranging in texture from the very light sands of the Lafayette and Columbia terrace formations, containing as little as 4 per cent. of clay in the subsoil, to the heavier lands of the Neocene formation, containing as much as 25 or 30 per cent. of clay.

The soils of northern and western Maryland have, as a rule, not less

than 25 or 30 per cent. of clay, and the finest grass and wheat lands in the limestone formations have as much as 40 or 50 per cent of clay. The soils of southern Maryland are, as a rule, distinctly lighter in texture than those of northern and western Maryland, and this undoubtedly explains the low average yield of wheat in this locality, as given in the table. This is clearly recognized by practical men acquainted with the two localities. They can not judge of the difference in the chemical composition of the soil; the area of the state is so small that there can not be great differences in climatic conditions, but they will say, from the general appearance of the land, that it is not as "heavy" as the finer wheat lands of western Maryland. It is not a matter of mere plant food; it is not because the preparation and cultivation in these Eastern Shore and southern counties are less thorough, but the land itself is too "light" to maintain a larger yield of grain or a permanent sod of grass.

It is quite possible in water or sand-culture, where the conditions of moisture, temperature, and aëreation can be perfectly controlled, to add sufficient plant food to the otherwise sterile medium for the production of a normal crop. If the conditions of moisture and temperature in the light, sandy truck lands or of the pine barrens of southern Maryland are favorable for the production of wheat, then it should be possible, as in sand-culture, to produce a crop of wheat, if sufficient plant food be added to the soil. But no one would suppose for a moment that the mere addition of plant food would enable a good wheat crop to be produced on this light, sandy land. It can not be economically produced on them under existing climatic conditions, unless vast quantities of organic matter were added to the land to change the whole character and texture of the soil and make it more retentive of moisture. If the soil cannot maintain a sufficient supply of water for the crop, then this becomes a controlling factor and limits crop production. We will show that these light lands of southern Maryland are not as retentive of moisture as the heavier wheat and grass lands of northern and western Maryland, and that this follows from the lighter texture of these soils, from which the practical farmer judges of the agricultural value of the land and the kind of crop which can be economically produced. It appears, therefore, that the controlling cause in the production of crops and in the local distribution of crops in these different soil formations in the state is largely due to the texture and general physical conditions of the soil, especially to their relation to water and the amount of water which they can maintain for the crop under existing climatic conditions.

A number of stations have been established in several of the principal soil formations of the state for the study of the moisture and temperature of the soil. The soils of the different formations have markedly different texture and are widely different in their agricul-

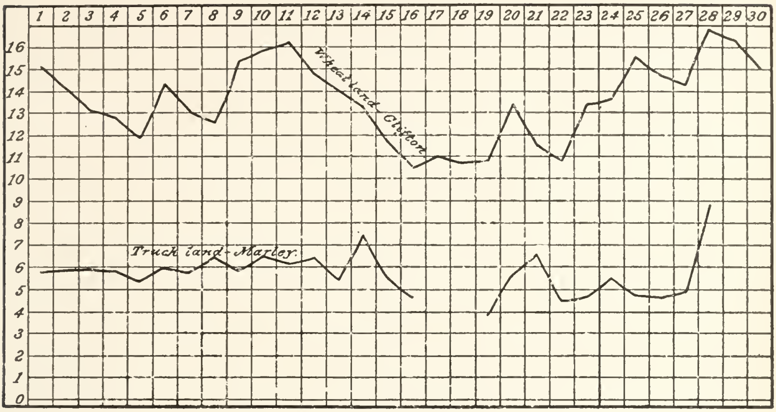
tural value. The stations are near volunteer observing stations of the Weather Bureau, or have the ordinary meteorological instruments supplied. They are not yet fully equipped, but are to have in addition to the above instruments a soil thermometer of a special construction, with a bulb 6 inches long, extending from 3 to 9 inches below the surface. It has a straight stem inclosed in a wooden case, as in the ordinary soil thermometer, but with maximum and minimum indices in the tube to register the highest and lowest temperature. The bulb has a special construction, devised by Professor Marvin of the Weather Bureau, to allow of the use of the two indices in the same stem. If the instrument is as successful as it gives promise of being it will be fully described at another time.

Moisture determinations are to be made in samples of the soil at the different stations, taken in small brass sampling tubes, $\frac{3}{4}$ of an inch in diameter and 9 inches long, with a mark on the side of the tube 6 inches from one end, which is the depth to which the sample is taken. Rubber caps are slipped over the open ends of the tube and it is put into a small bag and sent by mail. The moisture is determined by drying 50 grams of the sample in a porcelain dish in a water bath for five hours. The sample represents the first 6 inches in depth from the surface down. It would be well if the sample could be taken at a uniform depth of from 3 to 9 inches, or from 6 to 12 inches below the surface, but this is impracticable at these volunteer stations. It was decided that it would be impossible to secure uniform conditions if the soil were under cultivation or if any plants were allowed to grow on them, so that a small plot of land, at least 10 feet square, is reserved for this work. It is to remain undisturbed during the season, except that grass and weeds are to be removed by hand.

A convenient method is much to be desired for the determination of moisture in the soil without disturbing the natural position of the soil or removing or changing the instrument in any way. Various methods have been suggested and a number of the most promising methods were tried by Sturtevant, at Geneva, but none of them have been perfected. The writer has been trying to work out a method based on the change of electrical resistance of the soil with the changing moisture content. It is impossible, however, to get perfect contact with the soil and the plates, and it seems that this method can not be perfected. The method itself and the difficulties will be more fully discussed in another part of this report.

These moisture observations have not been continued sufficiently long to provide data for this report, but a single diagram is given showing the moisture in the soil in an open bed in the lawn at Clifton, where this work is located, and in the light, early truck lands at Marley.

Diagram showing the percentage of moisture in the wheat and truck lands.



The soil at Clifton is a fairly good wheat land, apparently about as strong as the better class of wheat lands of southern Maryland, although it belongs to an entirely different geological formation.

The soil from Marley represents the very light, early truck lands between Baltimore and Annapolis, which will be described in some detail in another part of this report. These samples were taken by Mr. T. W. Soley, of Marley, and sent by mail for the moisture determinations. Neither of the soils were cultivated nor disturbed in any way during this period.

The mechanical analysis has not been made of the soil at Clifton for the reason that the whole of the Potomac formation, to which it belongs, is extremely uneven. The moisture determinations, however, agree very closely with the moisture in samples from the Neocene wheat land at South River, which contains 17.87 per cent. of clay. The truck land from Marley has only 4.40 per cent. of clay.

The difference in the amount of moisture maintained by these two soils, as shown by the diagram, is probably amply sufficient to account for this local distribution of crops. Grass and wheat cannot be economically produced on a soil which can maintain much less water than that at Clifton, and certainly not in a soil which can only maintain as little as that at Marley.

These two localities are not over 8 or 10 miles apart in an air line, and the meteorological conditions could not have been very different. The "season" was very favorable at each place, the rainfall being rather more than the normal at both places. With the climatic conditions sensibly constant, we see here that these two soils maintain very different conditions of moisture for crops. Rain does the crop little or no good until it enters the soil. We see that one of these soils lets the rainfall pass through it readily and maintains not more than one-half or one-third as much moisture for the use of the

crop as the other. Each of these conditions, if artificially maintained in a greenhouse, would be distinctly favorable to some kinds of plants and unfavorable for the proper development of others. As stated before, if the conditions in this wheat soil at Clifton are normal and necessary conditions for the growth of wheat, which can not be doubted, then this inability of the light truck land to maintain a more abundant water supply, while distinctly favorable to the early ripening of truck, is a controlling factor in the economical production of wheat, and this relation of the soil to moisture becomes as potent a factor as a controlling cause in the local distribution of crops as temperature is in the general distribution of plants.

In the arrangement and classification of the samples of soil which have been obtained in Maryland, it appears that the staple crops are distributed according to the amount of clay and the approximate number of grains per gram contained in the subsoil, if the subsoil is of sufficient depth to regulate the drainage and to give character to the land, and if the grains can be assumed to have a mean symmetrical arrangement, as in most of our great soil formations. It appears that our staple crops are distributed according to the following percentage of clay in the subsoil, which, as has been shown, largely determines the texture of the soil and the relation of the soil to moisture: Barrens, less than 4 per cent.; early truck, 4–10 per cent.; tobacco, 14–18 per cent.; wheat, 18–50 per cent.; grass, 25–50 per cent. This applies of course only to the meteorological conditions which prevail in this State and when the grains are assumed to have the same symmetrical arrangement.

THE EARLY TRUCK LANDS OF SOUTHERN MARYLAND.

There is a narrow strip of coarse, sandy soils bordering the Chesapeake Bay from Baltimore down to South River, entirely devoted to the production of early truck and vegetables for the Baltimore and the larger northern markets. This same character of soil is found along the coast as far south as Florida, and on all of it truck is raised, but it is only of the small area between Baltimore and Annapolis that these remarks have special reference.

The coarse, sandy soils and subsoils of the early truck lands between Baltimore and Annapolis contain from 4 to 10 per cent. of clay. Other things being equal, the lighter the soil and the less clay it contains the earlier the crop. Soils having over 7 per cent. of clay are rather heavy for the earliest truck, but are well suited to tomatoes, cabbages, small fruits, and peaches. Geologically these light soils belong to the Columbia terrace formation, although there are good truck lands in this area on the Eocene soils which contain not over 8 or 10 per cent of clay and are excellent for peaches and the heavier truck. A large part of this area is lying out as a barren and unpro-

ductive waste for lack of proper facilities for transportation. This matter of cheap and quick transportation is so great a factor in the trucking interest, owing to the bulky and perishable nature of the market truck and small fruits, that lands directly on the water courses have a value many times greater than similar lands situated only a mile or two from the river.

Peas, tomatoes, cabbage, sweet potatoes, watermelons, canteloupes, strawberries, raspberries, and peaches may be grown, and are grown, with more or less success on nearly all kinds of soil. But this area of coarse, sandy land in southern Maryland will produce these crops at least a week or ten days earlier than the far heavier wheat and grass lands in other parts of the state. This puts the truck into the Baltimore and northern markets much earlier than it can be produced on the heavier soils of the state, and insures the early truck farmers from competition from the state at large, and they get very fair prices, as their crops are sold before the market prices fall with the glut of summer vegetables. It requires a very heavy outlay for manuring and for labor in the trucking business, and everything depends upon their getting their crop to market at the earliest possible date to take advantage of the high prices, and no pains or expense is spared to force the maturity of the plant and hasten the ripening of the crop.

The early truck lands are much too light for the profitable production of wheat or corn, or of any of the staple crops whose period of growth extends into or through the summer months, not because the soils are deficient in plant food, but because the soils are so coarse and open in texture that they are unable to maintain a sufficient water supply for these crops during the hot spells which are liable to occur. It is not that these light, sandy lands produce as much yield per acre of the different kinds of market truck as the heavier lands that they are utilized for trucking, but that they ripen the crops earlier and so get advantage of the higher prices. There are, therefore, peculiar conditions desired in an early truck land, just the opposite conditions, indeed, from those required for a good grass or wheat soil. The soil, or rather subsoil, of the truck lands should be very light in texture, containing not over 10 per cent. of clay, and for the very earliest truck not over 6 per cent. If they have more than this, the soil is too retentive of moisture, and the growing period is prolonged and the ripening of the crop is delayed. In the truck land with less than 6 per cent of clay, the soil is drier and probably cooler, and these are conditions which would hasten the maturity of the crop.

Other things being equal, the more clay a soil contains the more retentive of moisture it will be, and the greater the amount of moisture which would be maintained in the soil for the crop. The fine particles of clay not only make the spaces within the soil exceedingly small, so that the rainfall must pass downward very slowly through

the soil, but by increasing the area of the water-surface it increases the power the soil has of drawing water to the plant to supply the loss from evaporation and to replace that which has been used by the plant. In a heavy clay soil this supply of water may be so abundant as to prolong the growth of the plant and increase the size and yield per acre, but may greatly retard the ripening of the crop.

The average yield of wheat in Washington county is given by the census as 18 bushels per acre, and this is principally from a limestone soil having over 40 per cent. of clay. Wheat can not be economically produced on the light truck lands. It is not that the soils of Washington county contain necessarily more plant food than the truck lands of southern Maryland, but that having more clay the soils are stiffer and more retentive of moisture, and they can maintain a more abundant supply of water for the crop.

These limestone soils are too retentive of moisture for early truck. In an average season they would maintain such an abundant supply of water that, although large crops would be assured, the crops would be late in coming to maturity, and would come into competition with crops from all parts of the state. The light character of the land, therefore, gives the early truck planter a monopoly of the market.

The mechanical analyses of the subsoils from a number of localities will be given, with the surface area and the approximate number of grains per gram, with such notes as may be necessary on the agricultural value of these lands.

Mechanical analyses of truck subsoils from southern Maryland.

MARLEY NECK.

Diameter.	Conventional names.	471. Marley P. O.	472. Marley P. O.	591. 1 mile north of Marley P. O.	469. Glenburnie.	473. Albert Hammond.	590. 2 miles north of Marley P. O.
mm.							
2–1	Fine gravel	0.28	0.49	0.39	3.47	0.44	0.91
1–.5	Coarse sand	5.42	4.96	5.52	12.05	6.46	5.45
.5–.25	Medium sand	41.45	40.19	36.53	44.06	36.73	28.73
.25–.1	Fine sand	26.73	27.59	24.91	18.02	19.54	22.81
.1–.05	Very fine sand	12.46	12.10	11.79	9.59	10.28	13.44
.05–.01	Silt	7.22	7.74	9.89	5.73	13.42	14.77
.01–.005	Fine silt	2.21	2.23	4.51	1.37	5.61	4.29
.005–.0001	Clay	4.07	4.40	5.41	5.46	7.14	9.16
	Total	99.84	99.70	98.95	99.75	99.62	99.56
Organic matter, water, loss		0.16	0.30	1.05	0.25	0.38	0.44

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
471	Marley P. O	4.07	583	1,809,000,000
472	......do	4.40	615	1,955,000,000
591	1 mile north of Marley P. O	5.41	796	2,458,000,000
469	Glenburnie	5.46	654	2,406,000,000
473	Albert Hammond	7.14	987	3,215,000,000
590	2 miles north of Marley P. O	9.16	1,173	4,078,000,000

Mechanical analyses of truck subsoils from southern Maryland.

TICK NECK.

Diameter.	Conventional names.	585. Sandy land.	583. 1½ miles northeast of Armigers.	587. Loam.
mm.				
2–1	Fine gravel	0.45	0.28	6.06
1–.5	Coarse sand	10.33	6.09	22.09
.5–.25	Medium sand	46.29	39.48	29.87
.25–.1	Fine sand	20.15	23.00	9.82
.1–.05	Very fine sand	8.17	14.69	6.52
.05–.01	Silt	7.11	8.46	10.71
.01–.005	Fine silt	2.29	2.48	3.86
.005–.0001	Clay	4.77	5.01	7.89
	Total	99.76	99.45	96.82
Organic matter, water, loss		0.24	0.55	3.18

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
585	Sandy land	4.77	629	2,121,000,000
583	1½ miles northeast of Armigers	5.01	673	2,185,000,000
587	Loam	7.89	987	3,621,000,000

The soils from Marley Neck, having less than 6 per cent. of clay, as shown by the table, are considered very typical early truck lands. 473 is from a ridge of rather heavier land, having 7.14 per cent. of clay. The land where this sample was taken is considered rather heavy for the very early truck, but is excellent land for small fruits. The same may be said of 590, although less is known of this sample.

On Tick Neck, also, we find that the very earliest truck lands have less than 6 per cent. of clay. The sample of loam, 587, was taken far down on the point, in what is considered the garden spot of the truck area. There is a narrow strip of this loam soil extending along the bay shore and covering the points of these river necks. This strip is from one-half a mile to a mile wide, and contains considerable gravel in the subsoil about 2 feet below the surface. There are only small areas of the lighter sandy land containing less than 6 per cent. of clay. By reason of the location on the bay shore, with rivers and creeks making up in all directions into the farms, the climatic conditions are peculiarly mild and the truck planters are insured against frost. They can plant earlier so that these loam soils are as early, or earlier, than the light lands further up the river necks, represented by the other two samples in the table, although it is recognized by the truck planters that the period of growth is somewhat longer, and under exactly the same climatic conditions the crops would be later in coming to maturity on this loam soil than on the lighter sandy lands. It is, of course, a distinct advantage, however, to have both the heavier soil, which will produce more crop per

acre, and the favorable situation nearly surrounded by water to insure against frost and to allow the crops to be planted earlier.

Mechanical analyses of truck subsoils from southern Maryland.

ROCK POINT.

Diameter.	Conventional names.	579. Jas. Meek.	581. ½ mile north of McCubbins.
mm.			
2–1	Fine gravel	0.09	0.56
1–.5	Coarse sand	2.31	4.83
.5–.25	Medium sand	31.18	27.49
.25–.1	Fine sand	25.49	16.36
.1–.05	Very fine sand	16.92	12.51
.05–.01	Silt	12.86	22.39
.01–.005	Fine silt	3.82	5.03
.005–.0001	Clay	6.33	10.12
	Total	99.00	99.29
Organic matter, water, loss		1.00	0.71

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
579	James Meek	6.33	886	2,850,000,000
581	½ mile north of McCubbins	10.12	1,348	4,471,000,000

The two samples from Rock Point contain rather more clay than from the other localities, but very little is known of the agricultural features of these soils. 581 came from a ridge, and would be regarded as a decidedly heavier soil than 579, and better suited to small fruit.

Mechanical analyses of truck subsoils from southern Maryland.

NORTH MAGOTHY NECK.

Diameter.	Conventional names.	561. Armiger.	563. Armiger.	565. 2 miles west of Armiger.	567. 1 mile west of Armiger.	577. J. M. Cook.	589. 2 miles north of Armiger.	575. J. M. Cook, loam.	571. Dr. E. Williams, loam.	569. Dr. E. Williams, loam.	573. J. M. Cook, gravelly loam.
mm.											
2–1	Fine gravel	0.74	0.39	2.12	2.46	1.52	2.33	1.26	0.34	0.87	3.67
1–.5	Coarse sand	7.13	7.04	8.81	13.32	4.50	26.08	8.91	2.97	5.82	11.92
.5–.25	Medium sand	36.21	37.51	31.35	39.83	29.88	33.06	47.84	21.18	26.22	29.99
.25–.1	Fine sand	22.82	21.45	22.82	14.14	23.77	10.18	6.29	18.19	17.55	6.35
.1–.05	Very fine sand	14.15	13.45	16.76	9.34	10.36	4.71	6.29	17.17	16.34	5.56
.05–.01	Silt	9.26	10.72	10.19	10.17	17.16	13.14	15.08	21.05	16.33	21.91
.01–.005	Fine silt	4.68	3.72	2.08	3.29	3.83	3.58	5.76	9.57	7.45	6.21
.005–.0001	Clay	4.71	5.41	5.47	6.36	8.01	8.29	8.33	8.39	8.52	12.84
	Total	99.70	99.69	99.50	98.91	99.03	102.39	99.92	98.86	99.10	98.45
Organic matter, water, loss		0.30	0.31	0.50	1.09	0.97	......	0.08	1.14	0.90	1.55

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
561	Armiger	4.71	727	2,137,000,000
563	......do	5.41	769	2,427,000,000
565	2 miles west of Armiger	5.47	721	2,429,000,000
567	1 mile west of Armiger	6.36	824	2,856,000,000
577	J. M. Cook	8.01	1,060	3,596,000,000
589	2 miles north of Armiger	8.29	961	3,587,000,000
575	J. M. Cook, loam	8.33	1,102	3,676,000,000
571	Dr. E. Williams, loam	8.39	1,296	3,862,000,000
569	......do	8.52	1,204	3,869,000,000
573	J. M. Cook, gravelly loam	12.84	1,562	5,779,000,000

Of the samples collected on North Magothy Neck, the first four are typical early truck lands. They are very coarse, sandy soils, and in their natural condition they are little more than barren wastes. Under the peculiar and intense conditions of manuring and cultivation, however, they are admirably adapted to early truck and they are classed as the very earliest truck lands of the locality. 569 and 571 are of a loam soil from a ridge, similar to the ridge on Marley Neck where sample 573 was secured. Off of this ridge and down near the Magothy River, but on the same farm, the light lands prevail, containing not over 5 per cent. of clay in the subsoil. Dr. Williams stated that these light lands were his earliest truck soils, and that tomatoes, for example, will ripen at least a week earlier on the light lands than on the loam soil. Tomatoes and cabbages do better and yield more per acre on the loam soil, but they are not so early and, consequently, do not bring as good prices as the crops from the lighter soils. Time is everything to the early truck planter, and these light lands have some peculiar property which adapts them to this early truck and matures the crop earlier than on any other soils of the state. The loam soils are much better adapted to small fruits and peaches than the very light lands.

At the extreme end of Magothy Neck there are the same loam soils referred to in speaking of the soils of Tick Neck, of which 573 is considered a representative sample from this locality. There is considerable gravel in the subsoil about 2 feet below the surface. 575 and 577 are from lighter lands on the upper part of the same farm. These lighter soils are earlier than the heavier loam, but, by reason of the locality right on the bay shore and with rivers and creeks making up into the farm in all directions, this loam soil (573) is considered earlier than the loam soils at Dr. Williams, and probably as early as the lighter truck lands at Armiger. It is considered excellent for peaches and for truck, as it produces more per acre than the light lands, and, by reason of the location near the bay shore, the crop can be planted earlier and so will mature earlier than on even lighter lands further up the river neck.

Mechanical analyses of truck subsoils from southern Maryland.

SOUTH PATAPSCO NECK.

Diameter.	Conventional names.	467. Shipley.	476. Furnace Branch.
mm.			
2–1	Fine gravel	0.76	*2.80
1–.5	Coarse sand	8.55	8.36
.5–.25	Medium sand	35.04	26.11
.25–.1	Fine sand	19.26	10.72
.1–.05	Very fine sand	8.42	10.15
.05–.01	Silt	11.38	17.98
.01–.005	Fine silt	4.13	8.76
.005–.0001	Clay	10.59	11.60
	Total	98.13	96.48
Organic matter, water, loss		1.87	3.52

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
467	Shipley	10.59	1,244	4,767,000,000
476	Furnace Branch	11.60	1,549	5,386,000,000

* Including 1.08 per cent. larger than 2 millimeters.

The two samples from South Patapsco Neck show a larger percentage of clay than the lighter truck lands, and these soils are recognized as heavier lands and rather later than the early truck lands of Marley and Magothy. It is a great truck region, however, because it is adjacent to Baltimore, and the truck and vegetables can be taken to market by wagon at very much less expense and in better condition than if they were sent by boat or rail. These lands, also, can be depended upon for a constant supply of truck throughout the season, and while they come in competition more with truck from other parts of the state, still they have the advantage of more direct communication with the markets. Many of the truckers from this locality sell their products directly, without the intervention of middlemen or agents.

Mechanical analyses of truck lands from southern Maryland.

Diameter.	Conventional names.	270. South River Neck.	268. J. Birch.	145. Patuxent River.
mm.				
2–1	Fine gravel	0.32	0.04	1.78
1–.5	Coarse sand	5.81	1.97	7.63
.5–.25	Medium sand	40.63	28.64	38.35
.25–.1	Fine sand	28.93	39.68	21.80
.1–.05	Very fine sand	9.44	11.43	6.87
.05–.01	Silt	4.60	4.95	11.73
.01–.005	Fine silt	2.04	2.02	2.48
.005–.0001	Clay	7.63	8.79	7.92
	Total	99.46	97.52	98.56
Organic matter, water, loss		0.54	2.48	1.44

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
270	South River	7.63	903	3,450,000,000
268	J. Birch	8.79	1,007	3,955,000,000
145	Patuxent River	7.92	955	3,549,000,000

The two soils from South River Neck, represented in the table, are excellent truck lands and are particularly well adapted to peaches. The same may be said in a general way of the Patuxent River soils, but owing to the difficulty of transportation the soils represented by 145 have not been much improved.

These truck lands appear to be remarkably uniform in texture, and the slight differences, which appear in the percentage of clay and in the approximate number of grains per gram, are very sharply defined in the agricultural value and importance of the land. The soils having the lowest percentage of clay and the least number of grains per gram are, with the exception of those directly on the bay shore at the end of the river necks, invariably regarded as the earliest truck lands, and one can readily tell from the general appearance and texture of the soil to what class of lands the sample belongs. The light soils mature the crop earlier, but the heavier loam soils produce a larger yield per acre and generally a better development, and would be considered naturally stronger soils.

These soils are all too light for the profitable production of the staple crops, as the yield per acre would be extremely small and they could not compete with the stronger and heavier soils from other parts of the state and of the country. Their peculiar value lies in the fact that they can produce, during the spring and early summer, small fruits and vegetables earlier than they can be produced in other parts of the state, so that they have the advantage of good market prices. The reason for this is undoubtedly due to the physical structure of these soils, especially to the relation of the soils to water. It cannot be due directly to the amount of available plant food they contain, for no addition of mere plant food would make these soils as strong and productive as a limestone soil, unless the whole texture of the land was changed.

It has been shown in a diagram, page 53, that these light sandy soils can maintain, on an average, not more than 5 or 6 per cent. of water, and it has been shown that a good wheat land must maintain not less than 12 or 15 per cent. of water, and probably a good strong grass land should be able to maintain much more than this. These moisture determinations were made at Marley, near where samples 471 and 472 were taken.

A determination was made of the actual rate of movement of water through the subsoil in its natural position in the field, on Tick Neck, near where sample 583 was taken. The subsoil contains 37.29 per cent. of empty space and it took 3 minutes and 15 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches in depth of water.

A determination was made of the rate of flow through the saturated soil at Armiger (563). The subsoil contained 41.25 per cent. of empty space and it took 2 minutes and 30 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches of water.

A determination was made of the rate of flow through the saturated subsoil at Marley, near where samples 471 and 472 were taken. The subsoil contained 55.77 per cent. by volume of empty space; more than the samples from the other localities. An inch in depth of water passed through 3 inches in depth of the saturated subsoil in 1 minute and 30 seconds, under an initial pressure of 2 inches of water. In the wheat lands, as we will see later, the actual time required for an inch in depth of water to pass through 3 inches in depth of subsoil is very much longer than this, (43 minutes and over).

Stable manure is considered the very best fertilizer for these truck lands, and where this can be secured it is applied to the lands in large quantities. Lime is also largely used, but there must be sufficient organic matter in the soil for the lime to act on or it will "burn out" the land. Both the stable manure and lime, as we shall see later, would tend to make these soils more retentive of moisture, but the soils are so coarse and open in texture that large quantities of manure may be applied without fear of clogging the soil, and the effect of such manuring would be felt but a short time.

TOBACCO AND WHEAT LANDS OF SOUTHERN MARYLAND.

Tobacco and wheat have been staple crops in southern Maryland for many years. A grade of tobacco was produced there well adapted to the French and German markets, and large orders were placed with the Baltimore merchants for both of these countries.

It is claimed now that the lands have deteriorated from the continued cultivation of tobacco, and the quality of the tobacco is not so good as it was only a few years ago. Good prices may still be obtained for a good quality of leaf, but the prevailing prices are very low, as there is little market for the quality of tobacco generally produced.

It is claimed that the deterioration of these tobacco lands is largely due to lack of proper cultivation, owing to the scarcity and high price of labor, and to the lack of proper fertilization.

The wheat lands of southern Maryland, as stated in a previous sec-

tion, are lighter in texture than the wheat and grass lands of northern and western Maryland, and the average yield per acre is much less. It is claimed that these wheat lands have deteriorated within recent years for lack of proper preparation and treatment of the land, due to the scarcity and high price of labor, to the low price of wheat, and to the fact that much of the land has been heavily mortgaged for the past twenty-five years.

It used to be the rule to apply lime every five years, and to depend on this and clover to keep up the land, but this rule is being neglected. Lime is applied more rarely, as there is little money to spend on fertilization, and the lands are becoming clover-sick.

This deterioration of the lands can not be due solely to loss of plant food, for the deterioration is accompanied by a marked change in the texture and appearance of the land, which is very apparent to the eye. There is the greatest possible difference in the appearance of a well kept field and of a soil which has deteriorated. Some very interesting problems are presented in the changes which evidently occur in the texture of these lands in the deterioration of soils, or in the improvement of such as have been once worn out and abandoned.

The wheat soils of southern Maryland appear to be confined principally to the Neocene formation, and to the terraces bordering the rivers in the lower part of the peninsula, which are classed with the Columbia terrace formation, although the soil is very different from the light, sandy, truck lands of the Columbia formation bordering the bay. Tobacco is produced on both of these formations, and also on the Eocene soils. By far the largest and most important area of the wheat and tobacco lands, however, is in the Neocene formation, and it is those lands which will be considered here.

Wheat and tobacco are commonly grown on the same land, in rotation periods of two or three years. The best lands for wheat, however, are the heaviest clay lands, while the finest quality of tobacco is produced on the lighter loams. The heavy clay lands produce a larger yield of tobacco per acre, but the plant has a coarse, thick leaf, which is sappy, and which cures green and will not take on color. The finest grade of tobacco is produced on the lighter loam soils, which are rather too light for the profitable production of wheat. The tobacco produces a small yield per acre on these soils, but the leaf has a fine texture, and in curing it takes on a good color and brings a much better price in the market. As a rule, the lighter the soil in texture the finer the quality of tobacco produced and the higher price it will bring per pound, but the less yield there will be per acre, so that there is a limit in the profitable production of the very finest grades on the very lightest lands, as the price is not sufficient to cover the small yield per acre.

The accompanying table gives the mechanical analyses of the sub-

soils of tobacco lands from a number of localities in southern Maryland:

Mechanical analyses of subsoils from southern Maryland, rather light for wheat but the finest tobacco lands.

Diameter.	Conventional names.	266. Chaneyville.	258. Marlborough.	164. North Keys.	260. Nottingham.	262. Chaneyville.	162. Marlborough.
mm.							
2–1	Gravel	1.40	1.53	0.58	0.48	0.00	0.09
1–.5	Coarse sand	2.94	5.67	0.50	3.05	0.07	0.13
.5–.25	Medium sand	11.23	13.25	1.35	12.08	1.56	0.58
.25–.1	Fine sand	13.42	8.39	10.65	12.09	13.51	4.90
.1–.05	Very fine sand	19.32	14.95	37.71	19.17	37.73	26.78
.05–.01	Silt	17.59	28.86	22.00	23.09	18.82	33.12
.01–.005	Fine silt	5.44	7.84	7.81	8.74	6.18	8.24
.005–.0001	Clay	10.72	14.55	16.02	18.42	18.79	21.81
	Total	97.06	95.04	96.72	97.12	96.67	95.65
Organic matter, water, loss		2.94	4.96	3.28	2.88	3.33	4.33

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
266	Chaneyville	10.72	1,370	4,891,000,000
258	Upper Marlborough	14.55	1,902	6,786,000,000
164	North Keys	16.02	2,016	7,338,000,000
260	Nottingham	18.42	2,126	8,263,000,000
262	Chaneyville	18.79	2,197	8,530,000,000
162	Upper Marlborough	21.81	2,638	10,065,000,000

The finest quality of tobacco is produced on the soils shown to have the smallest amount of clay and the smallest number of grains per gram in this table, while the heavier soils are much better for wheat and give a larger yield of tobacco per acre, but the quality of the tobacco is not so good, and it does not bring as good a market price. With the exception of 162, none of these soils would be considered very good wheat lands with the ordinary conditions of cultivation and manuring. They would be considered rather too light for the economical production of wheat. These lands are valued for wheat in proportion to the amount of clay contained in the subsoils, as shown in the table, but for tobacco the values are just reversed.

The strongest and best wheat lands appear to be confined to the diatomaceous earth horizon of the Neocene formation. The white diatomaceous earth can be found a few feet below the surface at all, or nearly all, the localities represented in the accompanying tables. The yellow clay of the wheat land appears to have been formed by the weathering of this earth, as in a number of railroad cuts and river bluffs they are seen to merge together, and in all cases where air has had access to the diatomaceous earth through cracks and root holes, a thin layer of the yellow clay has been formed. Diatoms are still found in most of these samples of the subsoils of the wheat and tobacco lands.

There are two classes of wheat lands. On the ridges and high plateaus, where washing has not occurred to any extent, the lands are rather light and loamy, the loam being usually from 2 to 4 feet thick and overlying the heavier clay. These lands are better for corn than the heavier lands, but are not so good for wheat and are too light in texture for grass. Where the underlying clay is exposed, as in the gently rolling lands, it makes a much stronger and better wheat soil and good grass land. The accompanying table gives the mechanical analyses of the subsoils from a number of localities, which represent very fairly the wheat lands of southern Maryland:

Mechanical analyses of subsoils of wheat lands from southern Maryland.

Diameter.	Conventional names.	250. Chaneyville, J. F. Talbott.	248. Davidsonville, P. H. Isreal.	245. Davidsonville, opposite church.	180. Plum Point.	155. Upper Marlborough.	246. ½ mile west of Davidsonville.	141. Davidsonville, loam, T. S. Iglehart.	252. South River.	184. Popes Creek.
mm.										
2-1	Gravel	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00
1-.5	Coarse sand	0.07	0.22	0.28	0.00	0.40	0.56	0.23	0.25	0.46
.5-.25	Medium sand	0.98	2.76	0.98	0.48	0.57	31.26	1.71	3.39	6.61
.25-.1	Fine sand	12.22	12.85	1.74	3.06	22.64	4.62	6.08	10.65	12.19
.1-.05	Very fine sand	29.58	47.13	52.74	50.32	30.55	30.70	30.82	29.05	9.15
.05-.01	Silt	23.19	12.89	16.91	14.19	13.98	26.16	20.92	22.45	30.89
.01-.005	Fine silt	10.13	4.07	3.35	6.78	4.08	9.44	11.21	6.56	13.22
.005-.0001	Clay	19.14	19.19	19.57	20.28	21.98	22.53	23.78	23.92	24.45
	Total	95.31	99.11	95.82	95.11	94.20	95.27	94.75	96.27	96.97
Organic matter, water, loss		4.69	0.89	4.18	4.89	5.80	4.73	5.25	3.73	3.03

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
250	Chaneyville	19.14	2,453	8,918,000,000
248	Davidsonville, P. H. Isreal	19.19	2,097	8,452,000,000
245	Davidsonville	19.57	2,214	8,917,000,000
180	Plum Point	20.28	2,380	9,357,000,000
155	Upper Marlborough	21.98	2,493	10,228,000,000
246	½ mile west of Davidsonville	22.53	2,732	10,456,000,000
141	Davidsonville, loam, T. S. Iglehart	23.78	2,853	11,161,000,000
252	South River	23.92	2,681	10,933,000,000
184	Popes Creek	24.45	2,847	11,202,000,000

These lands make fairly good wheat lands, but it is about the limit of profitable wheat production, and a soil having less than 20 per cent. of clay, or approximately 9,000,000,000 grains per gram, is too light in texture and not sufficiently retentive of moisture for the economical production of wheat under the prevailing climatic conditions. This represents, however, merely the skeleton structure of the soil, and this could be so filled in and modified as to make it more productive, but experience has shown that a soil lighter than this has not sufficient body to warrant the expense of converting it into a good

wheat land. The soils are too light for grass. They are valued as wheat lands about in the order in which they are given in the table, except that it would seem that 245 should have been given a higher place in the table, as it is considered a very fertile wheat land, but this may have been due to the sampling.

A determination was made of the time required for water to pass through the subsoil at South River, near where 252 was collected. The subsoil was found to contain 51.48 per cent. by volume of empty space. One inch in depth of water passed through 3 inches in depth of saturated subsoil in 43 minutes, with an initial pressure of 2 inches in depth of water.

The samples in the accompanying table are of strong wheat and grass lands of southern Maryland. They are considered the very finest type of wheat lands in that locality:

Mechanical analyses of subsoils of strong wheat and grass lands from southern Maryland.

Diameter.	Conventional names.	142. Davidsonville, clay.	247. Davidsonville, James Iglehart	179. Herring Bay.
mm.				
2–1	Fine Gravel	0.00	0.00	0.00
1–.5	Coarse sand	0.00	0.27	0.00
.5–.25	Medium sand	0.29	0.64	0.50
.25–.1	Fine sand	2.43	3.20	3.50
.1–.05	Very fine sand	23.56	22.58	36.28
.05–.01	Silt	29.23	26.25	19.04
.01–.005	Fine silt	6.36	10.42	6.78
.005–.0001	Clay	32.45	32.40	32.42
	Total	94.32	95.76	98.52
Organic matter, water, loss		5.68	4.24	1.48

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
142	Davidsonville, clay, T. S. Iglehart	32.45	3,604	15,148,000,000
247	Davidsonville, James Iglehart	32.40	3,537	14,903,000,000
179	Herring Bay	32.42	3,389	14,433,000,000

These three samples were taken from very rolling lands, where the loam, if it had ever accumulated, had been removed by washing, leaving exposed the yellow clay which seems to underlie all the wheat lands.

Very recently the U. S. Geological Survey has made a geological survey of this locality, and from a manuscript map which they have kindly supplied it would appear that they have been able to separate the Neocene formation in this locality into Lafayette and Chesapeake. The Lafayette is shown as covering the high hills and plateaus, apparently where our loam samples were secured. The Lafayette formation is hardly more than 2 to 4 feet thick at this

place, and is made over out of the diatomaceous earth material, which would account for the diatoms found in the subsoil. The Lafayette formation covers the ridge lands further down the peninsula with the coarse, sharp sand of the pine barrens. This geological data will necessitate a further and more careful collection of soil samples in this locality, to see if these two grades of wheat land correspond closely with the two horizons of the Neocene formation; but this whole work shows the intimate relation of geology to agriculture, in the area and distribution of the principal soil formations and the necessity of thorough geological work as a basis for soil investigations.

There is a very marked relation between the agricultural value of these lands and the texture and general appearance of the soils. If the soils are in a moderate condition of cultivation, in which the arrangement of the grains can be assumed to be sensibly constant, the agricultural value increases quite regularly with the percentage of clay, and the approximate number of grains per gram. The yield increases, however, in nearly all cases, and with most crops, at the expense of the quality of the crop produced. In the case of tobacco and truck, as the quality or time of maturity is of more importance than the quantity of crop produced, the lands are valued, within certain limits, as the soil is lighter in texture and contains less clay and fewer grains per gram. It is not a matter of the chemical composition of the soil, or of the amount of available plant food in the soil, which determines this local distribution of crops, but it is a matter of the texture of the soil and especially of the relation of the soils to water, and the amount of water which they can maintain for the crop under existing climatic conditions.

Lime has been considered the very best fertilizer for these wheat lands, but lime with plenty of organic matter in the soil "for the lime to act on," otherwise, it will "burn out the land," so that where lime is applied, as it should be every few years, clover or some green manuring is considered a necessary adjunct. We shall see that this combination would tend to make the soils more retentive of moisture.

There has always been a peculiar prejudice against the use of high grade fertilizers in southern Maryland. They are rarely used on the wheat lands, especially where lime and clover can be applied. Large quantities have been used on the tobacco lands, but the deterioration of these tobacco lands is very frequently attributed to the use of the high grade fertilizers.

When Peruvian guano was introduced, as one of the first of the high grade fertilizers, it was used quite freely for tobacco, but it was claimed that it was, in the end, injurious to the lands. It was said that for the first two or three years it acted as a stimulant and increased the yield of crop, but that the land soon became exhausted and was

poorer than before. There has been no general recognition of this fact by agricultural chemists, for it has been argued that the continued application of plant food could not impoverish a soil, but it would certainly seem that the farmers were right in this, and that the injudicious use of high grade fertilizers may very likely have a permanent effect upon these soils, by changing the arrangement of the soil grains and changing the relation of the soils to water, which would be highly injurious to succeeding crops. This matter presents one of the most interesting problems in these soil studies of southern Maryland.

The samples which have been described and of which the mechanical analyses have been given in the foregoing tables, are of representative soils and from what is considered to be typical and representative localities of the different soil formations. Other samples have been collected of local interest, and there is a considerable amount of material on hand for the study of the change in texture which has evidently occurred in the deterioration of some of these lands, but there has been no time to work them up for this report.

WHEAT LANDS OF THE RIVER TERRACES.

The accompanying table gives the mechanical analyses of the subsoils from four localities of the fertile river terraces of southern Maryland:

Mechanical analyses of subsoils of wheat land.

RIVER TERRACE.

Diameter.	Conventional names.	199. Benedict.	201. St. Marys.	203. St. Marys.	205. Opposite. St. Marys.
mm.					
2–1	Fine gravel	0.38	0.44	2.01	0.41
1–.5	Coarse sand	2.72	1.05	5.24	0.42
.5–.25	Medium sand	11.64	2.67	1.75	1.64
.25–.1	Fine sand	7.23	5.03	2.17	3.45
.1–.05	Very fine sand	6.74	9.75	2.45	9.48
.05–.01	Silt	33.92	34.82	37.21	41.88
.01–.005	Fine silt	10.62	14.52	15.52	11.98
.005–.0001	Clay	23.45	25.03	29.27	26.24
	Total	96.70	93.31	95.62	95.50
Organic matter, water, loss		3.30	6.69	4.38	4.50

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
199	Benedict	23.45	2,765	10,737,000,000
201	Saint Marys	25.03	2,889	11,936,000,000
205	Opposite Saint Marys	26.24	3,188	12,205,000,000
203	Saint Marys	29.27	3,509	13,578,000,000

These river terraces border the Potomac River and its tributaries in the lower part of the peninsula, and are considered very strong

wheat lands. They are classed geologically with the Columbia terrace formation, but, as will be seen from the mechanical analyses and as shown from the agricultural value of the lands, they are very much stronger soils than those of the same formation on the bay shore, which form the early truck lands between Baltimore and Annapolis. The terraces have an elevation of from 20 to 60 feet above tide and are about $\frac{1}{2}$ mile wide, with the Lafayette formation rising beyond this into the pine barrens of the higher lands further inland. The lands have good body and are capable of a very high state of cultivation, and many of them are maintained in a very good condition. Some of the land around Saint Marys has been under cultivation for two hundred years without apparent deterioration, although there is nothing at all peculiar in the appearance of the land to indicate any unusual conditions. The soil is about 6 or 8 inches deep, but neither the soil nor subsoil appear to have more organic matter than is usual in the lands of southern Maryland, nor do they appear different from the same class of lands elsewhere. They have been taken care of and have been very intelligently handled.

TRUCK AND WHEAT LANDS FROM SHIPLEY.

Very interesting conditions, showing the relation of the texture of the soil to the local distribution of plants, are presented in the soils represented by their mechanical analyses in the accompanying table:

Mechanical analyses of truck and wheat subsoils—W. A. Shipley, Shipley Station.

Diameter.	Conventional names.	472. Early truck, Marley.	467. Truck and small fruit.	478. Peas, tomatoes, cabbage, wheat.	480. Strong wheat and grass.
mm.					
2–1	Fine gravel	0.49	0.76	2.05	0.00
1–.5	Coarse sand	4.96	8.55	3.31	0.38
.5–.25	Medium sand	40.19	35.04	5.41	1.07
.25–.1	Fine sand	27.59	19.26	2.89	0.78
.1–.05	Very fine sand	12.10	8.42	6.06	3.41
.05–.01	Silt	7.74	11.38	40.15	43.08
.01–.005	Fine silt	2.23	4.13	13.14	13.81
.005–.0001	Clay	4.40	10.59	23.84	30.21
	Total	99.70	98.13	96.85	92.80
Organic matter, water, loss		0.30	1.87	3.15	7.20

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
472	Early truck, Marley	4.40	615	1,950,000,000
467	Truck and small fruit	10.59	1,244	4,767,000,000
478	Peas, tomatoes, cabbage, wheat	23.84	2,242	10,923,000,000
480	Strong wheat and grass	30.21	3,479	14,457,000,000

472 represents the very early truck lands of Marley, which have already been described. Marley is about 3 or 4 miles in a direct line

from Shipley Station. The other three soils are all at Shipley Station, and are on the same farm and are only a few hundred feet apart, so that all the soils are under the same meteorological conditions. 480 is a strong grass and wheat land, from a ridge having an elevation of about 160 feet. This sample was taken in a heavy grass sod which has stood for a number of years. It would be classed anywhere as a strong wheat soil and a very good grass land. 478 came from a level plateau or terrace, just under the ridge, and was evidently formed of the same material. It is a much lighter soil than that on the top of the ridge, but is still a good wheat land. It is too heavy for early truck and for sweet potatoes and canteloupes. It is considered good tomato, corn, and cabbage land, although it does not ripen the crops so early as the lighter soils. Peas do well on this land, but they cannot be grown two years in succession, for the large amount of nitrogenous matter in the roots and vines makes the soil very close and heavy, and the second year there is a large amount of pea vines but a very small crop of peas is obtained from them. Wheat is nearly always sown after the peas, then grass, followed by corn, and then peas again. Some such rotation as this is necessary to keep the land open and in good condition. 467 is the regular truck land of this locality, well suited to truck and small fruit. It is a coarse, sandy soil, but not so light in texture nor as early as the lands at Marley. The productiveness of these lands increases with the amount of clay they contain and the number of grains per gram.

It cannot be doubted that the local distribution of plants on these soils is due to the texture of the land, and very largely upon the relation of the soils to water. No better illustration can be found of the fallacy of a very common impression of the theory of fertilization than in these soils. It is not that the strong clay soil (480) is necessarily deficient in any particular kind of plant food that sweet potatoes and canteloupes cannot be successfully grown, and further, if sweet potatoes and canteloupes are to be grown upon this land the conditions of treatment should be just the reverse of what would be required for the best development of wheat. For the melons the soil must be made more loamy and less retentive of moisture, while for wheat and grass the soil must be made, if anything, closer and more retentive of moisture. Tomatoes raised on a heavy soil, like (480), in which there is such an abundant water supply, would be likely to run to weed, that is, to produce a very large and rank growth of vine but with little fruit, and it would be late in coming to maturity, just as in a greenhouse a florist can make a geranium bloom quite freely by keeping the soil rather dry, or he can push it to a luxuriant development of foliage, with no tendency to flower, by keeping the soil more moist. Obviously, the same treatment could not be expected to have the same results for all crops on any one of these soils, and the same

plant might require very different conditions of manuring and treatment on these four different soils.

It would be admitted by practical men that 467 is well adapted to small fruits, but that 472 is rather light in texture and 480 is too heavy for the best development of such a crop. Obviously, the treatment best adapted to one soil would not give the same results on the other, for the conditions of growth which it is desired to secure would be a mean between these two extremes.

SAMPLES OF CLAY.

Very interesting conditions are found in the Potomac formation; a narrow belt of barren clay hills extending across the state from Washington through Baltimore to the Delaware line. These variegated clays are so close in texture as to be almost impervious to water, and quite unsuited to the growth of agricultural crops. The movement of water through them is so extremely slow that a plant would suffer for lack of sufficient water while the soil might show a high water content. The clay is used at the potteries for burning both porous tile and stoneware, and it is so impervious to water that it is used for puddling and for diverting water from the gutters in the repair of streets.

The accompanying table gives the mechanical analyses of three samples of clay:

Mechanical analyses of samples of clay.

Diameter.	Conventional names.	304. Red clay, tile.	305. Red clay, puddling.	288. Helderberg limestone.	303. Blue clay, stoneware.
mm.					
2–1	Fine gravel	0.00	0.31	1.34	0.00
1–.5	Coarse sand	0.00	0.82	0.33	0.00
.5–.25	Medium sand	0.50	2.69	1.08	0.29
.25–.1	Fine sand	2.63	3.23	1.02	1.27
.1–.05	Very fine sand	9.62	8.89	6.94	8.93
.05–.01	Silt	25.13	26.17	29.05	20.16
.01–.005	Fine silt	13.44	11.18	11.03	16.72
.005–.0001	Clay	42.34	42.36	43.44	50.02
	Total	93.76	95.65	94.23	97.39
Organic matter, water, loss		6.24	4.35	5.77	2.61

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
304	Red clay, tile	42.34	4,737	20,072,000,000
305	Red clay, puddling	42.36	4,566	19,447,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
303	Blue clay, stoneware	50.02	4,905	22,639,000,000

There is also given, for comparison, the mechanical analysis of a very strong and fertile wheat subsoil of the Lower Helderberg formation. It will be seen that this is almost identical in texture with the red

clay used in puddling. The impervious clays have no more of this fine material in the clay group, and no more grains per gram than the limestone soil, but the one is too close in texture and too retentive of moisture, and will dry into a hard, stone-like mass, while the other, although a strong clay soil, is friable and readily permeable to water.

A few drops of strong ammonia added to the water which passes through the limestone soil will make this quite as impervious as the other clays, and this change in the texture of the soil will be due to a rearrangement of the soil grains, the change being quite apparent to the eye. There is no question but that the trouble with these impervious clays is that they are too close and too retentive of moisture, and that this is due, not to an unusual amount of clay, but to the arrangement of the soil grains. To increase the agricultural value of these lands they must be made lighter in texture and less retentive of moisture, and this can probably be done by the judicious use of fertilizers and manures, accompanied by underdrainage and proper conditions of tillage and cultivation; on the other hand, it will be no very difficult thing, by injudicious fertilization or treatment of the land, to convert the limestone soil into an impervious clay which would be turned out as a barren waste.

The whole problem of the soils, as presented in southern Maryland, makes it appear that the deterioration of lands is due to or is accompanied by a change in the arrangement of the soil grains, changing the relation of the soil to the circulation of the water. This change in the appearance or texture of the land is quite apparent to the eye, and one can judge of the condition of the land by the general appearance of the soil.

It would appear as a result of this work that the subsoil of good grass land under prevailing climatic conditions should contain not less than 30 per cent. of clay, or about *twelve thousand million* grains per gram, good wheat land not less than 20 per cent. of clay, or about *nine thousand million* grains per gram, and early truck not over 10 per cent., or about *four thousand million* grains per gram; *provided*, these grains have a certain mean arrangement, and that this skeleton structure contains an average amount of organic matter.

It has taken a long time to collect this material and arrange and classify it to give a basis for further work. It has not been possible to go over the field and make the actual determinations of the rate of flow of water through these subsoils, except in the few cases which have been given, and in working up the methods in the laboratory. This is the most important work to be taken up, now that the material has been collected, and if the opportunity is given this will be the next line of work to be undertaken, to study the actual relation of these soil formations to water and the effect thereon of manures and fertilizers.

Until this work is done and the actual determinations of the rate

of flow can be given it will be unnecessary to give in detail the calculated relative rate of movement of water through these different soils.

There has not been sufficient work done as yet in the soils of western Maryland to permit of a fuller discussion than will be given in the type samples.

TYPE SUBSOILS.

A number of type samples have been prepared and analyzed, showing the average composition of all the samples collected from the principal agricultural soils in southern and western Maryland, as shown in the accompanying table.

Mechanical analyses of type subsoils.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	290. Oriskany, "fine earth."	280. Wheat.	278. River terrace.	282. Triassic.	238. Catskill, "fine earth."	289. Shales, "fine earth."	288. Helderberg limestone.
mm.											
2–1	Fine gravel	*4.87	1.34	1.36	0.64	0.00	1.60	0.00	0.00	0.05	†1.34
1–.5	Coarse sand	9.15	8.24	2.13	0.81	0.42	1.51	0.23	0.11	0.16	0.33
.5–.25	Medium sand	38.37	34.77	7.78	3.50	1.81	4.15	1.29	0.42	0.80	1.08
.25–.1	Fine sand	33.28	19.94	16.57	23.97	8.59	4.84	4.03	2.63	2.01	1.02
.1–.05	Very fine sand	3.52	11.11	19.83	34.76	32.06	8.54	11.57	11.35	6.70	6.94
.05–.01	Silt	3.47	12.15	25.41	10.03	23.65	44.92	38.97	40.23	31.63	29.05
.01–.005	Fine silt	1.55	4.17	4.52	3.03	6.77	5.78	8.84	10.90	14.24	11.03
.005–.0001	Clay	3.75	7.45	17.95	20.30	22.85	25.85	32.70	33.32	39.36	43.44
	Total	97.96	99.17	95.55	97.04	95.85	97.19	97.63	98.96	94.91	94.23
Organic matter, water, loss		2.04	0.83	4.45	2.96	4.15	2.81	2.37	1.04	5.09	5.77

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
276	Pine barrens	3.75	496	1,692,000,000
284	Truck	7.45	971	3,266,000,000
286	Tobacco	17.95	2,102	8,258,000,000
290	Oriskany, "fine earth"	20.30	2,173	9,154,000,000
280	Wheat	22.85	2,602	10,358,000,000
278	River terrace	25.85	2,924	11,684,000,000
282	Triassic red sandstone	32.70	3,593	14,736,000,000
238	Catskill, "fine earth"	33.32	3,669	14,839,000,000
289	Shales (Hamilton, etc.), "fine earth"	39.36	4,411	18,295,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
....	Trenton chazy limestone	53.02	5,574	24,653,000,000

* This includes 1.81 per cent. coarser than 2 millimeters.
† This includes 0.82 per cent. coarser than 2 millimeters.

The tables are substantially as published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, except that it has been found that a sample containing a large percentage of clay had been accidentally introduced into the truck type, and so few localities were represented that this made a great difference. The present type of truck soil is from twenty-eight localities. This table includes all of the principal agricultural soils in southern and western Maryland, except the very important soil of the Trenton limestone forma-

tion, represented here by only a single sample, but it does not include any of the soils of the Eastern Shore or any of the soils of the crystalline rocks of the Piedmont Plateau in northern-central Maryland.

The soils thus arranged according to the amount of clay they contain and the approximate number of grains per gram, which gives the texture of the soil, are arranged in the order of their relative agricultural value.

The approximate extent of surface area, in square centimeters per gram, is given in detail in the accompanying table for a number of the soil types and the approximate number of grains per gram, to show the relative value of each of the separations.

Surface area (sq. cm.) per gram of subsoil.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.	279. River terrace.	282. Triassic red sandstone.	288. Helderberg limestone.
mm.								
2–1	Fine gravel	0.5	0.2	0.2	0.0	0.2	0.0	0.1
1–.5	Coarse sand	2.8	2.5	0.7	0.1	0.5	0.1	0.1
.5–.25	Medium sand	23.6	21.2	4.9	1.1	2.6	1.0	0.7
.25–.1	Fine sand	43.9	26.0	22.4	11.6	6.4	5.3	1.4
.1–.05	Very fine sand	10.8	33.8	62.5	100.9	26.5	35.8	22.2
.05–.01	Silt	26.7	92.5	200.7	186.2	348.7	301.4	232.7
.01–.005	Fine silt	47.7	127.0	142.8	213.2	179.5	273.5	353.4
.005–.0001	Clay	339.8	667.3	1,668.0	2,089.0	2,360.0	2,976.0	3,965.0
	Total	495.8	970.5	2,102.2	2,602.1	2,924.4	3,593.1	4,575.3

Approximate number of grains per gram of subsoil.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.
mm.					
2–1	Fine gravel	7	3	3	0
1–.5	Coarse sand	160	142	38	7
.5–.25	Medium sand	5,356	4,794	1,114	258
.25–.1	Fine sand	45,700	27,050	23,320	12,050
.1–.05	Very fine sand	61,380	191,500	354,500	571,200
.05–.01	Silt	945,900	3,270,000	7,101,000	6,588,000
.01–.005	Fine silt	27,030,000	71,830,000	80,790,000	120,700,000
.005–.0001	Clay	1,664,000,000	3,267,000,000	8,170,000,000	10,230,000,000
	Total	1,692,088,503	3,342,323,489	8,258,269,975	10,357,871,515

Diameter.	Conventional names.	278. River terrace.	282. Triassic red sandstone.	288. Helderberg limestone.
mm.				
2–1	Fine gravel	3	0	12
1–.5	Coarse sand	26	4	60
.5–.25	Medium sand	583	181	157
.25–.1	Fine sand	6,701	5,556	1,456
.1–.05	Very fine sand	150,200	202,600	125,900
.05–.01	Silt	12,340,000	10,670,000	8,231,000
.01–.005	Fine silt	101,600,000	154,900,000	199,900,000
.005–.0001	Clay	11,570,000,000	14,570,000,000	19,430,000,000
	Total	11,684,097,513	14,735,778,341	19,638,258,585

It will be seen from these tables that the clay group has a most important influence on the texture of the soil, as shown in these calculations. In the extent of surface area it is far ahead of the other separations, although the effect of the coarser grades is still quite apparent. In the approximate number of grains per gram, which, according to these views, determines the extent of subdivision of the empty space in the soil, the clay group has by far the greatest value, and this and the fine silt practically determine the real texture of the subsoils, provided the grains have the same mean arrangement. The reason for this is found in the extremely small size of the grains of clay, so that a percentage of clay means a vast number of soil grains and a very large extent of surface area.

Assuming the amount of empty space for these subsoils, as given, the relative rate of flow of water through a certain depth with a uniform water content (12 per cent.), is given in the accompanying table, as calculated by the formulæ already given.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	12	8
284	Truck	45	12	16
286	Tobacco	50	12	33
290	Oriskany	50	12	35
280	Wheat	55	12	45
278	River Terrace	55	12	49
282	Triassic	55	12	56
238	Catskill	55	12	58
289	Shales (Hamilton, etc.)	60	12	81
288	Helderberg limestone	65	12	100

With this uniform water content, if an inch in depth of water passed through the Helderberg limestone in 100 minutes, it would take about 45 minutes for the same quantity of water to pass through the type of wheat land of southern Maryland. With the same rainfall, therefore, and the same amount of water falling on each of these soils, the water will pass down through the light lands much quicker than through the heavier soils, providing the soils are short of saturation.

Some time after a rain when the excess of water had passed down through the light lands, and the rate of movement was about the same in all of the soils, the water content of these lands would be about as given in the next table.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	5.3	101
284	Truck	45	6.2	103
286	Tobacco	50	8.4	102
290	Oriskany	50	8.6	101
280	Wheat	55	9.4	100
278	River terrace	55	9.6	100
282	Triassic	55	10.0	101
238	Catskill	55	10.1	100
289	Shales (Hamilton, etc.)	60	11.2	100
288	Helderberg limestone	65	12.0	100

This would be approximately the relative amount of water found in each of these subsoils some time after a soaking rain, and it agrees very well with the few actual moisture determinations which have been made in these soils. There is little doubt that these values, based on purely theoretical considerations, will be sustained, in the main, by actual moisture determinations and that they will give an expression of the texture of the land. The mean arrangement of the grains in the undisturbed subsoil of these great formations is probably not very different, except in special cases, as in the impervious clays of the Potomac formation or for local conditions, and it is probable that the amount and condition of the organic matter in the undisturbed subsoil of these great soil areas are sensibly constant and that their effect will not greatly differ, except under artificial conditions of cultivation and manuring.

There are undoubtedly exceptions to this, as may be seen very plainly in the Potomac clays and in the shales in the western part of the state, but these exceptions are due to conditions which can be readily recognized and which, indeed, are made apparent by the departure of these soils from the conditions which have been assumed.

The relations of these soils to water as shown by these calculations, and as it is believed will be shown by actual moisture determinations, are as different as in the artificial conditions of greenhouse culture.

In greenhouse culture the development of the plant can be largely controlled by judicious watering. Water may be readily added or withheld from different classes of plants, or for different kinds of development as needed, and the whole art of greenhouse culture is in the judicious control of the temperature and the moisture of the soil. Different classes of plants undoubtedly require different treatment for their best development. In field culture water can not be so readily added or withheld for certain classes of plants or for certain kinds of development, but we find that under the same rainfall these different soil formations have such different relations to water that they are able in themselves to maintain very different conditions of moisture for the plants, quite as different as in the artificial conditions of greenhouse culture, so that the conditions in these different soil formations are best adapted to particular kinds of plants; and we have here, it would appear, the reason for the local distribution of plants under prevailing climatic conditions.

It may be suggested that if water can move through the light truck lands, containing 5 per cent. of moisture, in the time it moves through the heavier limestone soils, containing 12 per cent. of water, as shown in these calculations, that the light truck lands should be able to supply the wheat crop with sufficient water as readily as the heavier clay soil; but when water descends in the soil the forces pulling it down are surface tension and gravity. But where it has to be pulled

up to the plant the only force to pull it up is the surface tension, and this has to act *against* gravity. There is much less water surface to contract in the light, sandy lands, so that if 100 pounds of water are needed by the wheat crop in a given time there will be very much less water surface to contract—that is, much less force to pull the weight of water up to the crop in the light land than in the heavier soil.

Another interesting problem is suggested here in the application of these principles to the study of the relation of the soils to water. If the empty space within the soils is completely filled with water, as in a perfectly saturated soil, the amount of space will be an important factor in the rate with which this water can be removed, and the light, sandy lands, having much less space and a much smaller capacity for water, may be slower than the heavier soils in draining off the excess. This is shown in the accompanying table, and may very likely account for the matter of very common experience that crops suffer more in excessively wet seasons in light lands than they do on heavier soils.

No.	Soil.	Space.	Water-content (saturation).	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	20.10	74
284	Truck	45	22.41	87
286	Tobacco	50	27.42	121
290	Oriskany	50	27.42	130
280	Wheat	55	31.55	109
278	River terrace	55	31.55	119
282	Triassic	55	31.55	137
238	Catskill	55	31.55	140
289	Shales (Hamilton, etc.)	60	36.14	123
288	Helderberg limestone	65	41.22	100

These calculations of the relative rate with which water will move within these different subsoils are based solely on the skeleton structure. The influence of the organic matter is not considered, and the soil grains are assumed to have the same mean arrangement. These two factors, the amount of organic matter and the arrangement of the soil grains, are probably nearly alike under the normal conditions which prevail in these great soil formations, as has already been pointed out, but if they have not the same effect in the different soils they will undoubtedly make the difference in the relations of these soils to the circulation of water still wider than the values we have assigned. Each of these factors requires a distinct line of investigation, and this is necessary to the practical use and application of this work.

If it is thought that not sufficient importance has been given to the chemical composition of the soils in this treatment of the subject, it must be remembered that if it is admitted that the judgment of the practical farmer of the value of his lands is based on the general ap-

pearance or texture of the land which determines the relation of the soil to water, then this factor is the controlling cause of plant growth and distribution, and is of first importance in the treatment and improvement of the land, and it is only through the study of the texture of the soil that the theory of fertilization will be made clear.

EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

In the improvement of a soil the question should be asked, how do the conditions differ from the best conditions for the kind of crop or the kind of development desired, and this question must be answered by the effects which are usually very apparent to the eye. The soil may be too dry or leachy, or it may be too retentive of moisture. This may be apparent to the eye in the texture of the soil, or it may be shown in the growth, vitality, and development of the plant.

Take the case of the soil from the sand hills of South Carolina, which has been referred to in a previous section. The growth of the plant is very small, but it puts on a large amount of fruit in proportion to the size of the plant and the amount of food material which has been stored up, and it ripens the crop quite early. Both of these latter qualities are very desirable. The size of the plant, however, shows that the soil is either not sufficiently retentive of moisture, or it is so very retentive and impervious that it can not supply the moisture fast enough for the needs of the plant. The texture of the soil shows that the soil is not sufficiently retentive of moisture, and that it is in this direction, rather than the other, that the trouble lies, and that to improve the condition of the land this soil must be made more retentive of moisture. On the other hand, the red land is rather too close and too retentive of moisture; it maintains such an abundant supply of water that the plants develop a very large amount of foliage and grow to a large size, and while they produce a large yield per acre of seed cotton, there is not nearly so much crop produced in proportion to the amount of food material stored up as with the crop on the sandy land. There is a tendency also for the crop to be late in maturing. It requires a careful diagnosis to determine what is the trouble with the land, just as a physician must be able to judge from the symptoms what is the cause of the trouble with the patient; and he must act on this for the improvement of the system.

In greenhouse culture, an experienced florist can tell from the development and appearance of the plant whether it has received the proper treatment; and so with field crops, from the appearance of the plant, the kind of development, the texture of the leaf, the vitality of the plant, and the diseases or insect ravages to which it is subjected, all are very plain indications of the conditions of the soil, and it is from these symptoms that one must judge of the cause of the trouble,

and it is in this line that the improvement of the land must be worked out.

To change the physical condition and texture of a soil so as to make it more retentive of moisture, there are two possible lines of procedure which may be clearly recognized and defined. The soil grains may be pushed further apart, not necessarily so that the volume of empty space will be increased, but that the fine grains of clay shall be pushed further out from the larger grains of sand, so that the grains will have a more symmetrical arrangement within the soil, or, if the grains have already such an arrangement as to give the full value to the clay, this skeleton structure can be filled in with organic matter by precipitation of organic matter within the soil.

The first of these principles can be illustrated in the opposite effects of ammonia and lime on fine particles of clay suspended in a liquid. If a drop of the turbid liquid containing a trace of ammonia be placed under the cover glass of a microscope, the fine particles of clay suspended in the liquid can not come close together, or, if they do, they are repelled. If, on the other hand, a trace of lime is added to the turbid liquid, the fine particles of clay and silt gather together in light flocks, and can not only approach each other, but are held together by some force.

The effect of ammonia in rearranging the grains in the soil has already been referred to. It is very probable that the chemical composition of the soil moisture will determine the distance apart of these fine silt and clay particles, so that they may come closer together when some fertilizers are added to the soil, or be pushed apart when others are applied. These movements could readily take place in a soil containing only a moderate amount of moisture, for the film of water around the grains would be much thicker than the diameter of the grains of clay, so that the latter would be immersed in what would be, relatively, a liquid of some depth.

This matter can probably be made the subject of experimental verification, and, indeed, the apparatus has been ready here for some time to determine this point, whether two surfaces immersed in a liquid can come closer together under a constant weight when certain fertilizing materials are present than when others have been dissolved in the water. Measurements of this kind are to be made, as preliminary work to the study of the effect of fertilizers on the arrangement of the soil grains. Fertilizers are certainly known to have some such physical effect as this on the soil, although the cause has never been worked out in this detail, nor has the effect itself ever been considered much in soil investigations, in the effect it would have on the soil and crop.

The effect of organic matter in retarding the rate of flow and making the soil more retentive of moisture, is much more apparent than the

rearrangement of the soil grains. If a filtered extract of stable manure is poured on to a soil contained in a glass tube, the organic matter will be precipitated in light, flocculent masses within the soil, and the liquid will run through quite colorless. If the coarse, sandy soil of the sand hill formation in South Carolina, or of the truck lands in Maryland, are to be improved, there is nothing so good as stable manure to apply to the land, especially if the soil is already quite deficient in organic matter, as is usually the case. If a quantity of such a soil be placed in a glass tube with a cloth tied over the under end, and a filtered extract of stable manure poured on the soil, the liquid will pass through quite colorless, and the rate of movement will get slower and slower until, if sufficient organic matter is used, the soil can be made quite impervious to water.

The precipitation of the organic matter from solution, and the segregation of the solid matter into light, flocculent masses, can be watched through a microscope focused against the side of the tube.

If coarse, sharp building sand is used, the organic solution may pass through unaffected, but if lime or some other fertilizing materials are added to the sand, the precipitation occurs as in a soil proper. If the lime is mixed with the upper inch of sand, this will assume the dark appearance of a soil resting on a light, sandy subsoil, with a sharp line of demarkation between them, so that in such a soil, naturally deficient in lime and iron compounds, an application of lime or of some similar substance which coagulates the organic matter would be necessary to bring out the full effect of the organic manuring. As a matter of fact, there is no soil which responds so readily to lime as these light, sandy lands, when sufficient organic matter is added,or is present, for the "lime to act on."

The lime precipitates the nitrogenous matter of the stable manure from solution, and in this case, at any rate, it is this coagulated nitrogenous matter which makes the soil more retentive of moisture, and it is this nitrogenous matter, alone, of all forms of organic matter, which is valued as a fertilizing material. There seems no reason to doubt that if the carbo-hydrates were readily precipitated from solution in these light, flocculent masses that they would have the same effect in retarding the rate of flow of water through soils and in making the soil more retentive of moisture, and that they would then have nearly the same agricultural value.

Many organic substances can be coagulated or precipitated from solution by lime or various alkaline or saline bodies, while others would not be affected by these, but would be coagulated by acids and a different class of material. With this view of the matter, therefore, it would not be expected that different forms of organic matter would have the same effect on the same soil, or that the same kind of organic matter would have the same effect on different soils. This view of

the matter makes it evident why stable manure and lime have always been given a value out of all proportion to the amount of plant food which they contain, and why a comparatively small application of these and other fertilizing materials often has an effect on the crop out of all proportion to the plant food they contain.

Some experiments have been carried on to study this effect of fertilizers on the movement of water through soils, both in the laboratory and in the field. In the laboratory, 8-inch Argand lamp chimneys have been used, 2 inches in diameter. A subsoil containing 26 per cent. of clay has been used in most cases, and a depth of 6 inches with 50 per cent. by volume of empty space. In the field work the fertilizers were thoroughly mixed with the soil to a depth of 6 inches, and samples will be taken in the undisturbed subsoil from below this for the actual determination of the rate of flow of water several times during the growing season. The work has not progressed far enough to be discussed in detail in this report, but it is giving very interesting results, and showing a very marked effect of fertilizers on the relation of soils to water.

One interesting fact brought out in these laboratory experiments is that when successive quantities of water are passed through a soil in a tube the rate becomes slower and slower. In one case, with 47 per cent. by volume of empty space in the soil, the rate decreased from 57 minutes to 169 minutes when eight successive quantities, of 100 cubic centimeters of water each, had been passed through. Another time, with 50 per cent. by volume of empty space, the rate decreased from 36 minutes to 265 minutes when eighteen successive quantities, of 100 cubic centimeters of water each, had been passed through. When a filtered extract of stable manure was passed through a similar lot of soil the rate decreased to about 2,000 minutes after six successive quantities of the extract had passed through, and the rate became so slow that the work could not be carried further. Lime or muriate of potash when added to the soil alone had little effect on the rate of flow, but seemed to increase it a little. When lime was added to the soil and an extract of organic matter then passed through, the rate at first was slower than when the lime had not been added, but it did not decrease as rapidly when successive quantities of organic extract had been passed through, and lime, acid phosphate, and kainite seemed to prevent the very marked effect of the organic matter alone; so, while lime or some similar substance is necessary to bring out the effect of organic matter in a sharp building sand, still, in the presence of lime and in this soil containing 26 per cent of clay and presumably a considerable amount of iron compounds, the organic matter did not have nearly as much effect on the soil when lime was present as when it was applied alone. It would seem that there must be some such dif-

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ference to explain the difference in the effect of lime on stiff, heavy clays, and on light, sandy soils.

Dried blood, dried tankage, dried fish, and cotton-seed meal all had a very marked effect in retarding the rate of flow. Ammonium sulphate decreased the rate, but not very much; nitrate of soda decreased the rate very remarkably, and made the soil almost impervious to water. This can hardly be due to a precipitation, as in the case of the organic matter, and must, probably, be due to a rearrangement of the soil grains, as in the case of ammonia.

These results are preliminary and are not sufficient for a detailed discussion, but they certainly point out a very remarkable effect of these fertilizing materials on the texture of the soils and the relation of soils to water, and point out a line of work which will be necessary for the interpretation of the results of plot experiments, and for working out the true theory of fertilization.

The soil appears to a casual observer as a coarse and inert mass, popularly known as "earth" or "dirt"; it seems hardly as though it could be affected by any simple change of conditions. It is, on the contrary, extremely sensitive to even unappreciable changes of conditions, and the relation of soils to water is so extremely sensitive that there is little wonder that the soil is often injured by injudicious treatment, but the wonder is that it is not more often ruined by the treatment it receives.

In this moisture work it is extremely difficult to fill the same tube twice over with a similar soil and the same amount of empty space, and have the flow of water agree closely, and this is the more difficult the heavier the soil is. If the soil is moistened before being loaded into the tube the rate of flow of water will be quicker up to a certain point with the amount of moisture the soil contained, showing that the grains had a different arrangement, and that the fine grains of clay were held more closely against the larger grains of sand.

The following results show this very plainly, the same kind of soil was used in all cases and contained about 26 per cent. of clay, the same tube was also used. Three hundred and fifty grams of soil were mixed with the requisite amount of moisture and loaded into the tube so that it should be 6 inches deep and contain 47.4 per cent. of empty space. The soil was then saturated and the rate of flow observed.

Grams.	Space.	Moisture.	Rate.
	Per cent.	*Per cent.*	*Minutes.*
350	47.4	0	128
350	47.4	2	65
350	47.4	3	60
350	47.4	4	45
350	47.4	6	36
350	47.4	8	27

There is a limit to this, of course, for when the soil contained too

much water the grains were pushed out and the water went through much more slowly.

The rate of flow becomes much slower if the soil is left standing in the tube for a few days. Then, unless just the proper amount of empty space is left in the soil, the soil will either swell or contract when it is saturated with water. Even in the determinations of the flow in the soil in its natural condition in the field, if the sample is taken when the soil is dry it will often swell somewhat after it is imbedded in the paraffine and saturated with water.

These changes are extremely subtle and it is impossible, oftentimes, to detect any reason for the change. The addition of pure water or of fertilizing material may often change the rate of flow to a very remarkable extent. This whole work indicates that instead of being an inert mass the soil is extremely sensitive to all changes of conditions and is full of life and movement.

If these forces can be directed and controlled they are amply sufficient to bring about any desired change in the arrangement of the soil grains, and of the texture of the soil, and it remains to find out how these conditions can be most successfully controlled, or how best to take advantage of them in the improvement of the land.

A METHOD FOR THE DETERMINATION OF MOISTURE IN THE SOIL.

It is extremely desirable that a method be devised for the determination of the moisture in the soil, without removing a sample from the field.

A method which has given promise of good results is based on the changing electrical resistance between two plates, permanently buried in the soil, with the changing moisture content. But it seems to be impossible to secure good contact between the soil and the plates.

The method, as first devised, consisted of burying alternate plates of zinc and copper in the soil, and reading the deflections of a galvanometer when contact was made between the zinc and the copper plates. The deflections were far greater when the soil was wet than when it was dry, but polarization took place so rapidly that satisfactory readings could not be taken.

After this, copper plates were buried some distance apart and a current sent across from one to the other and the resistance measured, but this also was unsatisfactory. Finally an induction coil was used, and a Wheatstone bridge arrangement, with a telephone instead of a galvanometer. Copper plates were at first used to bury in the soil, then carbon, and lastly mercury, contained in clay or in flat porous cells such as is used in batteries.

The plates are put so far apart that the resistance is about 1,000 ohms when the soil is in "good condition" or contains about 8 or 10 per cent. of water.. As the soil dries the resistance increases up to

1,500 or 2,000 ohms, and when it is saturated, after long continued rains, the resistance falls to about 200 ohms. The resistance regularly falls with increasing temperature, but the effect is far greater than for any known temperature coefficient.

When the plates are inclosed in sealed jars so that the water content remains constant, the resistance is constant for any temperature, even after the plates have remained undisturbed for a year or more. When the water content changes, however, the resistance gradually increases, so that when the soil is repeatedly wet and dried the resistance becomes much higher for any given condition of temperature and moisture.

It appears that the soil moves away from the surface of these foreign bodies. The soil presses against the plates with increasing temperature, and, the contact being better, the resistance is lower; as the temperature falls, however, the soil is withdrawn and the resistance rises. With changing moisture content the soil gradually compacts within itself and pulls away from the plates, and the resistance gradually increases.

In pot culture where the soil is contained in glass jars the soil becomes more compact and pulls away from the glass sides of the jar, leaving a considerable space between the soil and the sides of the jar. This is not so noticeable with porous earthenware pots, so it was thought that possibly the form or nature of the surface of the foreign body had something to do with this movement, and it was for this reason that carbon plates were substituted for copper. Such plates have been buried now for a year, and the resistance does not seem to have permanently increased, but every day the resistance rises and falls with changing temperature, as will be shown in the accompanying table.

It was thought that this movement might only occur at the surface of the foreign body, and it was attempted to imbed these carbon plates in clay and burn them in a porous tile. This could not readily be done, however, and then mercury was tried; first, by moulding a form of a plate in the soil, in moulding sand, or in clay, but much trouble was found in the liquid filtering down into the soil. The mercury was then put into flat, porous cells, and these were buried in the soil, but these also show the effect of changing temperature. As it has been shown in another way that the soil actually moves away from these foreign bodies and that this movement may continue for a long time, if the movement is followed up, it is evident that the mercury would give no better results if put directly in the soil than the carbon plates have given. There was this advantage in using the mercury instead of a rigid plate, that the mercury would follow the movement of the soil and maintain good contact. We have found, however, that with any yielding substance of this kind the movement

would continue, and the indications are that the soil would contract or move away indefinitely from the foreign substance.

There seems to be no way to overcome this difficulty or to secure good contact with the soil, and it seems as though for this reason the method could not be perfected, but the indications it has given of this movement in the soil are of very great interest and value, and perhaps quite as important as the method itself would have been.

The accompanying table gives the readings for about three months of a series of carbon plates which were buried in the soil about a year before these readings were taken. There are three plates connected together on each side, each plate being 3 by 12 inches, and the two sets of plates were buried about 18 inches apart, the top of the plates being two inches below the surface of the ground. Rather more than the average amount of rain fell during this time and the soil has been unusually moist. During a prolonged drought the resistance of these plates would probably go up to 1,500 or 2,000 ohms.

Actual determinations have been made for part of the time of the amount of moisture in the soil, and the temperature of the soil as well as the principal meteorological conditions, but these are not given as they are hardly necessary in the present stage of the work. The important point to be worked out first is to secure the proper contact between the soil and plates and to overcome the extreme sensitiveness of this system to the natural movements within the soil.

Electrical resistance of the soil in ohms.

Date.	April.			May.			June.		
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.
1	....	....	....	280	260	305	165	170	220
2	....	....	....	330	315	355	227	227	285
3	....	....	....	345	335	380	270	245	280
4	....	....	....	400	355	337	285	255	265
5	....	....	....	387	365	440	250	255	200
6	....	....	....	462	407	377	200	220	255
7	....	....	....	417	395	500	270	255	270
8	....	....	....	535	450	530	265	200	158
9	....	....	....	....	450	520	160	....	....
10	....	....	....	605	485	499	140	140	145
11	....	....	....	300	260	245	155	150	180
12	510	430	510	255	255	301	180	160	200
13	595	470	539	309	280	325	200	200	200
14	595	560	350	320	310	....	255	235	265
15	310	265	265	185	180	150	290	....	....
16	320	270	325	160	155	185	300	295	295
17	300	285	300	200	190	210	335	315	285
18	270	257	240	245	220	225	295	275	....
19	255	200	250	220	160	155	270	270	300
20	260	250	244	170	150	167	300	....	260
21	220	220	220	160	160	....	290	280	300
22	220	200	200	160	....	165	315	305	330
23	210	195	210	170	160	182	....	180	200
24	200	190	205	200	175	203	220	215	....
25	235	225	245	220	195	234	150	....	175
26	250	220	267	245	225	175	200	200	230
27	285	245	300	155	150	165	220	220	135
28	330	315	340	175	149	160	135	135	149
29	315	265	250	175	170	175	150	150	151
30	265	220	270	175	160	150	178	125	....
31	....	....	....	155	160	165	....	....	....

A MOVEMENT OF SOIL GRAINS.

As it seemed probable from the variations in the electrical resistance of the soil that there was a movement of the soil grains this matter was made the subject of experimental investigation.

A thin rubber ice bag with a capacity of, approximately, 1,000 cubic centimeters, was securely fastened to a rubber stopper bearing a 60 cubic centimeter separating funnel for the admission of water, and a small tube, with an internal diameter of about 3 millimeters, which projected about 2 inches above the surface of the ground, and was then bent horizontally for about 18 inches in length, and was graduated the whole extent into eighths of an inch.

The rubber bag was about one-third filled with water and buried in the soil, the soil being pressed around the bag so as to force the water up into the small tube. The tube being horizontal maintained a constant pressure whether the bag expanded or contracted, and when the water fell in the tube, as it did almost every day, water was added through the separating funnel. This arrangement insured a constant pressure in the bag, and if there was any tendency for the soil to move away the bag would expand and follow it. The bag was buried in about 200 pounds of soil contained in a large tub and was kept in one corner of the laboratory in the house in Clifton, which is very solidly constructed. The soil was a mixture such as would be used in greenhouse work. There was no convenient way of determining the quantity of water in the soil, so it was watered from time to time and was kept in a fair condition for a growing plant.

This apparatus has been standing for nearly 4 months, and nearly every day water has to be added through the separating funnel to bring the level in the tube to the zero mark. It is set every morning, and, as a rule, the water gradually rises during the day and begins to fall in the afternoon and continues to fall during the night.

The movement is not constant, but seems to depend on meterological conditions. During a long rainy spell the water in the tube is generally beyond the zero point, and often during such periods it remains beyond the zero point for several days at a time; when the weather clears, and especially when there is a sudden change to clear, cold weather, the liquid falls in the tube very rapidly. Indeed, this movement is so extremely sensitive that it is frequently noticed that a change to stormy or fair weather could usually be depended on by the indications of this movement, often a day or two in advance of the actual change; that is, when the level of the liquid in the tube was over the zero mark persistently in fair weather, dull, rainy weather would nearly always follow within a day or two. On the other hand, in continued dull, rainy weather, with no apparent signs of clearing, the level of the liquid in the tube would very often begin to fall perhaps a day or two before the actual change occurred.

It was believed that these changes were dependent upon meteorological conditions, and there were indications both here and in the variation of the electrical resistance of the soil which seemed to show that this movement was largely dependent upon the changing atmospheric pressure as well, of course, as upon changing temperature. There seems to be no very simple relation, however, between the movement of the soil grains and the readings of the ordinary meteorological instruments, but still there does seem to be a relation between the movement of these soil grains and climatic changes.

One source of error which would hide any such close relation is in the extreme sensitiveness of the apparatus. At first, at any rate, before the soil became very compact in the tub, any one walking across the floor in the vicinity of the tub, or the least touch of a finger on the side of the tub, or a clap of thunder that would jar the tub, could be plainly recognized in their effect in the fall of the liquid in the tube. After the first few days the effect of this was hardly appreciable, but still it is impossible to say what effect they continued to have. A similar arrangement was buried in the soil of the field when this work was first started in South Carolina, but this was found also to be so extremely sensitive as to be affected by a footstep even a considerable distance away. The level of the liquid in the tube would rise and fall with the pressure of the foot on the ground.

When the apparatus was first set up the level of the liquid fell very rapidly whenever water was added to the soil, and it was believed that the repeated changes in moisture content was really the principal cause of the movement. As the soil became more compact, however, it was found that water could be added to the soil without materially affecting the level of the liquid in the tube. This was rather unexpected, as the movement still continued from other causes.

Fearing that the rubber sack which had been used in this instrument was rather thin, and that water was liable to get through the sides in one way or another, some other bags were made to order out of heavy, pure rubber cloth. The bags have a capacity of about 500 cubic centimeters, and were tested for several days, as was the other, in fact, before being set up. This apparatus was put into a very large, wide-mouthed glass packing bottle, and was put down in the basement, on a wide stone window-sill, where it was supposed it would be perfectly free from jar or disturbance of any kind, as the walls of the building are about two feet thick.

The jar is fitted with a manometer, and arranged so that the temperature or pressure can be varied at will, to study the effect of these conditions on the movement. The soil was put in air-dry, being pressed around the bag as before until the liquid rose into the tube.

The apparatus has been set up for very nearly two months, and the soil has not been watered during this time. The movement, however,

goes on in this air-dry soil and the water is constantly falling in the tube as the soil compacts within itself and the bag expands. The level in the tube regularly rises every day above the zero point, and falls in the afternoon and night. But the total fall is greater than the rise, and water has to be added through the separating funnel to bring the liquid in the tube to the zero point. It must be remembered that the rise and fall of the water in the tube here referred to is not a vertical rise and fall which would vary the pressure, but is a horizontal flow, so that the pressure in the bag is constant.

This movement in the dry soil will be watched for a considerable time before water is added to the soil or the conditions are changed in any way, for it is a matter of very great interest. Similar apparatus will be planted out in the field, and the effect of stirring the soil or of cultivation will be studied.

This rubber bag, while flexible and adapting itself to marked changes of the soil, still can not follow any detailed movement as a growing root could, or develop in the line of greatest movement and of least resistance, but the whole side of a bag, or a large area, must move together, and this movement will depend upon the smallest movement of the soil grains. It seems certain, however, that the soil is moving away from these rubber bags, and the bags themselves, under a constant pressure from within, are slowly enlarging, and that the same forces that cause this movement may act in the development of roots through the soil, so that it would not be necessary to conceive of a root forcing its own way through the hard subsoil, as the soil itself will materially aid this development by a movement away from the surface of the root. This movement of the soil grains must have an important bearing on the development of roots through the soil, and the nature of the root surface and the matter which it exudes may have an important effect on the movement itself.

The accompanying table gives the readings of the apparatus in the soil in the tub for three months, with the temperature of the soil, and the very complete meteorological data for March from the records of the Weather Bureau observer in Baltimore. The meteorological instruments are located about 2½ miles in an air-line from Clifton, so that the results can not be as directly applied as though the observations were taken closer. The readings of the instrument are given in eighths of an inch, which was the graduation of the tube, and the last column gives the daily rise or fall in the tube in inches. The instrument was set at 8 a. m. each day by letting in water through the separating funnel to bring the water in the tube to the zero mark, but when the water was already beyond this point the instrument was not set.

Readings of the apparatus for three months.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a.m.	1 p.m.	8 p.m.	8 a.m.	1 p.m.	8 p.m.	8 a.m. to 8 a.m.
March 1	59	....	....	0	....	−1	−1.37
2	60	62	59	−5	−3	....	−1.00
3	59	60	....	−22	−4	....	−3.25
4	59	62	64	−17	−6	−10	−2.00
5	64	64	64	−7	−5	−2	−1.47
6	59	59	60	−78	+2	+2	−12.00
7	57	60	62	−23	−1	+11	−2.90
8	61	62	64	+7	+3	+4	+0.87
9	62	64	65	−10	−1	+1	−2.12
10	63	65	66	−13	−3	−9	−1.62
11	60	61	64	−71	−1	−2	−8.87
12	57	60	62	−20	−4	−3	−2.50
13	59	59	58	−9	−11	−24	−1.12
14	57	58	58	−43	−2	−3	−5.33
15	57	59	60	−16	0	+6	−2.00
16	57	61	61	+23	+20	+19	+3.62
17	57	61	62	+10	+4	+12	−1.62
18	55	58	56	−1	−14	*	−1.37
19	55	58	59	....	....	−10	−59.00
20	55	56	58	−78	+2	+2	−12.00
21	55	58	59	−30	−8	−15	−3.75
22	53	59	61	−32	−4	−10	−4.00
23	59	62	65	+7	+5	+15	+0.85
24	61	63	64	−7	−7	+2	−1.75
25	62	64	66	−13	−136*	−1	−1.62
26	62	63	64	−13	−7	−26	−18.36
27	62	62	61	−52	−8	−27	−6.50
28	58	61	64	−55	−12	−2	−6.90
29	61	62	63	−17	−5	−4	−2.13
30	60	63	66	−23	0	+11	−2.87
31	62	64	64	−9	−5	−10	−1.12
Mean	58.6	61	62	....	....	....	−5.32
Total fall	....	....	....		(24.75 *cc.*)		−165.00

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a.m.	1 p.m.	8 p.m.	8 a.m.	1 p.m.	8 p.m.	8 a.m. to 8 a.m.
April 1	62	65	67	−26	−1	0	−3.25
2	66	67	68	−1	−17*	−29	−0.12
3	69	71	71	−38	+1	+11	−4.75
4	71	71	71	+1	−17	−14	+1.25
5	70	70	71	−82	−2	−6	−10.25
6	70	70	67	−34	−7	−13	−4.25
7	66	68	67	−84	+3	+3	−10.50
8	64	66	66	−26	+1	+1	−3.25
9	62	63	60	−20	−7	−24	−2.50
10	55	55	55	−55	−6	−11	−7.00
11	53	56	59	−68	−1	+6	−8.40
12	57	59	62	+10	+2	+10	+1.25
13	59	60	58	+7	+4	+4	+0.37
14	59	62	64	0*	0	−1	−0.87
15	58	61	61	−15	−7	−1	−1.87
16	58	61	62	−23	−1	+5	−2.87
17	59	60	60	−12	0	0	−1.50
18	58	62	67	−25	−7	−4	−3.12
19	63	66	66	−17	−1	+9	−2.12
20	63	64	64	−6	0	+3	−0.75
21	63	64	64	−7	−3	−5	−0.93
22	61	64	65	−17	0	+4	−2.12
23	63	68	65	−4	−1	+10	−0.50
24	64	67	67	−12	+3	+11	−1.50
25	64	65	64	−5	−6	−5	−0.62
26	62	63	63	−19	0	+2	−2.37
27	60	63	65	−11	+1	+9	−1.37
28	63	66	67	+12	+11	+18	+1.50
29	66	67	69	+19	+16	+15	+2.37
30	66	66	65	+1	−1	0	−2.25
Mean	62.4	64.3	64.6	....	....	....	−2.35
Total fall	....	....	....		(10.58 *cc.*)		−70.59

*Added water to soil.

Readings of the apparatus for three months—Continued.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m. to 8 a. m.
May 1	63	65	65	—16	0	+ 7	— 2.00
2	65	69	70	+ 3	+ 6	+17	+ 3.70
3	68	72	73	+13	+17	+19	+ 1.25
4	68	69	71	+18	— 5	+ 9	+ 0.62
5	68	69	69	— 1	— 3	— 8	— 2.12
6	67	69	71	—80	+ 4	+10	—10.00
7	67	68	65	— 7	— 5	— 4	— 0.87
8	62	63	62	—26	— 1	— 3	— 3.25
9	....	64	63	....	—20	+ 7	— 2.50
10	62	63	63	— 4	0	+ 4	— 0.50
11	63	65	66	— 4	— 2	+ 3	— 0.50
12	65	64	65	— 3	— 3	— 6	— 0.37
13	64	65	65	—20	+ 1	+ 8	— 2.50
14	63	64	....	— 7	— 4	....	— 0.87
15	64	65	66	—16	+ 3	+ 7	— 2.00
16	66	69	70	+ 9	—16	+26	+ 1.12
17	69	69	69	+21	+21	+26	+ 1.50
18	67	69	68	+18	+17	+19	— 0.27
19	68	69	68	+21	+21	+12	+ 0.27
20	66	68	60	0	+ 2	+ 6	— 2.62
21	64	65	....	— 6	— 9	....	— 0.75
22	62	....	61	—24	....	+ 3	— 3.00
23	62	63	62	— 3	+ 2	+ 4	— 0.27
24	62	63	63	0	— 1	+ 3	0.00
25	64	65	66	+ 2	+ 4	+10	+ 0.25
26	66	68	69	+12	+14	+22	+ 1.25
27	68	66	66	+18*	+26	+26	+ 0.75
28	63	63	63	+14	+14	+16	— 0.50
29	64	65	66	+ 2	+ 3	+ 1	— 1.50
30	66	68	70	—14	0	+ 2	— 2.00
31	69	71	72	—24	+ 1	0	— 3.00
Mean	65.1	66.5	66.4	....	....	....	— 0.97
Total fall	....	....	....		(4.54 *cc.*)		—30.28

* Added water to soil.

Meteorological data from the station at Baltimore for March, 1892.

Date.	Pressure.			Temperature.					Relative humidity.			Absolute humidity, grains per cubic foot.		
	8 a. m.	8 p. m.	Mean.	8 a. m.	8 p. m.	Max.	Min.	Mean.	8 a. m.	8 p. m.	Mean.	8 a. m.	8 p. m.	Mean.
	Inches.	*Inches.*	*Inches.*	°	°	°	°	°	*Pr.ct.*	*Pr.ct.*	*Pr.ct.*			
1	29.80	29.97	29.88	35.1	34.0	37	34	36	99	95	97	2.379	2.126	2.252
2	30.09	30.22	30.16	29.5	31.0	32	30	31	90	90	90	1.674	1.817	1.746
3	30.15	30.06	30.10	31.0	38.0	43	28	36	74	62	68	1.476	1.674	1.575
4	30.01	29.86	29.94	38.5	48.0	55	35	45	52	66	59	1.415	2.563	1.989
5	29.85	29.87	29.86	41.1	34.5	42	34	38	88	86	87	2.563	1.969	2.266
6	30.00	29.96	29.98	34.0	41.0	46	32	39	67	53	60	1.540	1.606	1.573
7	30.00	29.92	29.96	37.5	46.0	57	34	46	66	65	66	1.745	2.379	2.062
8	29.61	29.32	29.46	39.5	44.0	47	39	43	96	96	96	2.659	3.189	2.924
9	29.44	29.61	29.52	41.0	50.0	54	38	46	100	55	78	2.967	2.292	2.630
10	29.66	29.73	29.70	41.5	33.0	50	33	42	96	80	88	2.862	1.817	2.340
11	29.92	30.02	29.97	21.0	28.5	32	20	26	59	62	60	.806	1.138	.972
12	30.00	29.88	29.94	29.0	49.5	61	25	43	57	52	54	1.090	2.126	1.610
13	30.03	30.07	30.05	35.0	31.0	36	30	33	72	95	84	1.745	1.892	1.818
14	30.30	30.31	30.30	24.0	29.0	34	24	29	50	78	64	.772	1.476	1.124
15	30.41	30.34	30.38	25.9	33.5	35	25	30	53	58	56	.878	1.298	1.088
16	30.40	30.33	30.36	22.8	29.5	31	23	27	93	68	80	1.355	1.298	1.326
17	30.38	30.15	30.26	25.0	25.0	27	24	26	63	100	82	.999	1.606	1.302
18	29.82	29.69	29.76	27.3	30.0	31	24	28	89	84	86	1.540	1.606	1.573
19	29.91	29.90	29.90	24.1	34.5	39	23	31	62	58	60	.957	1.415	1.186
20	30.17	30.30	30.24	29.1	34.0	38	29	34	62	53	58	1.190	1.243	1.216
21	30.53	30.52	30.52	22.0	31.0	34	21	28	60	54	57	.841	1.090	.966
22	30.54	30.31	30.42	26.5	37.0	38	23	30	72	74	73	1.190	1.892	1.541
23	30.03	29.98	30.00	41.5	51.0	65	37	51	92	62	77	2.862	2.659	2.761
24	30.24	30.15	30.20	38.0	42.0	50	35	42	53	69	61	1.415	2.208	1.812
25	30.17	30.05	30.11	41.5	50.0	56	34	45	71	55	62	2.208	2.292	2.250
26	29.94	29.75	29.84	44.0	44.0	48	43	46	78	100	89	2.563	3.306	2.934
27	29.46	29.65	29.56	44.0	39.0	44	39	42	100	96	98	3.306	2.659	2.982
28	29.95	30.09	30.02	40.8	44.0	50	39	44	68	63	66	2.046	2.126	2.086
29	30.29	30.26	30.28	39.9	43.0	53	36	44	52	74	63	1.540	2.379	1.460
30	30.33	30.23	30.28	37.9	44.5	47	35	41	42	52	47	1.138	1.817	1.479
31	30.26	30.37	30.32	39.6	40.0	42	39	40	90	100	95	2.563	2.862	2.712